Measuring the value of the movement of people and goods to inform the One Network Road Classification functional categories criteria

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Contents

Executive summary

This research project aimed to explore and test measurable criteria for the economic value of the movement of people and goods for use in the One Network Road Classification (ONRC) and contribute to the development of a performance measurement framework. The ONRC was developed to support:

- value for money and consistency in asset management and investment decision making across road controlling authorities throughout the country
- provision of a consistent 'customer experience' for road users across the country: 'over time, road users can increasingly expect to have similar experiences across the country, on roads in the same category' (NZ Transport Agency 2013, p4).

The ONRC functional classification criteria are a range of measures which aim to approximate the role of a road in moving people and goods, eg annual average daily traffic (AADT), heavy commercial vehicle (HCV) AADT, buses per hour and a notional active modes criterion. The criteria also aim to capture the economic and social role of roads (eg linking populations, and serving ports, airports, tourist locations and hospitals). Overall, the criteria aim to categorise roads into hierarchical groups which indicate the functional importance of the road.

Our assessment of the ONRC functional classification criteria found that the current traffic volume-based metrics are likely to introduce bias to the overall passenger movements. Specifically, the criteria for public transport (PT) usage (the number of buses per hour or movements of people per hour) does not necessarily relate very closely to the number of PT passengers. As a result, the importance of PT corridors is likely to be understated in large urban areas.

We also found there could be an overestimation of freight movements in PT corridors, as buses are counted as HCV, which could also bias the overall freight movement in PT corridors in large urban areas.

Our assessment also found that the proxies used for economic productivity are underdeveloped. The relationship between traffic volumes and economic output is indirect. Our research aimed to develop, for use in the ONRC, measurable criteria with a more direct relationship to economic output. We explored indicators which could be used in conjunction with the current ONRC functional classification criteria. For the long term, we developed a framework to assess the absolute productivity of roads, which could be used to replace the current ONRC functional classification criteria. We completed the research in three phases:

- a literature review
- exploration of an economic framework for the criteria
- testing and application of the framework to case studies.

A review of the literature showed there are typically three scales for analysis of links between road infrastructure and economic productivity: 1) national (macro), 2) regional (meso) and 3) local (micro). We found that analysis at a local, small area level was the most appropriate for understanding the road's contribution to economic activity. This is the scale of analysis undertaken by MWH in 2012, who developed an economic framework to estimate the role of roads with respect to rural land use and relationship to production facilities and to the port based on GIS modelling.

In order to develop the framework, we investigated the data which could be used. Understandably, there are gaps in the data in terms of coverage (eg geography, time). A key challenge in developing new measures for roads' contribution to economic productivity is data availability. Throughout the project, we sought to balance ambitions for indicators that could provide accurate and new information, while working within constraints associated with data availability, appropriate analytical effort and practical feasibility. We focused on exploring new measures that could conceivably be widely adopted in practice, given existing data availability. Nevertheless, all our new measures explored in this research would require further work in data collation and analysis.

The framework we developed captures the inputs and the outputs of roads, as a measure of the productivity of roads.

$$Productivity = \frac{Outputs}{Inputs}$$

Roads do not produce economic output but are an input to economic production. The outputs of roads can be measured reflecting the variety of uses for the road, including:

- total people movements (for all trip purposes)
- total public transport passenger movements
- commute movements
- freight movements.

Applying appropriate weights on trips made for specific purposes provides a more direct relationship to economic output. For example, weighting commuting trips by the income of the traveller, provides an estimate of the economic value-added (in terms of the returns to labour) enabled by the road.

Similarly, weighting freight movements by the market price of goods provides an estimate of the total value of the goods which is being moved along a road.

Following the framework developed by Small and Verhoef in 2007, we propose a broad scope for the inputs of roads, including fixed costs and variable costs – regardless of whether they accrue to users or non-users.

Combining the output measures and input measures, the following productivity indicators were explored as potential indicators for future use in the ONRC:

$$Freight\ productivity = \frac{Freight\ output\ measure}{total\ road\ input\ costs}\ or\ \frac{HCV}{total\ road\ input\ costs}$$

$$Public\ transport\ productivity = \frac{PT\ users}{total\ road\ input\ costs}$$

$$Total\ passenger\ productivity = \frac{Vehicle\ users + PT\ users + cyclists + pedestrian\ volumes}{total\ road\ input\ costs}$$

$$Commute\ productivity = \frac{Commute\ output\ indicator}{total\ road\ input\ costs}$$

The four productivity indicators above are relative productivity indicators, therefore the productivity estimated must be compared to a benchmark. If the indicators are adopted, we recommend establishing a benchmark database against which the productivity of road segments is compared. These could be used **within** current ONRC functional classification categories (eg compare roads within the primary collector roads category) to determine whether road segments are ‘high relative productivity’ or ‘low relative productivity’, which could be used for road renewals and maintenance purposes, or in transport planning more broadly.

None of the four indicators consider the place function of roads or streets, or the welfare impacts of use of transport. For example, leisure trips will contribute less to economic output than trips taken for business purposes, all else equal, but leisure trips are an important component of welfare. The economic framework we have explored focuses on the relationship of the road to activity producing economic outputs and the resources consumed in generating that output. Our focus has not been on transport network efficiency, which has a different focus (eg throughput, optimal speed, safety, travel times, accessibility).

Over the long term, we recommend moving towards a measure of absolute productivity, which can be aligned more easily to performance measurement targets. We have explored the concept of a second-best, alternative route indicator, which estimates the opportunity cost of a road segment. A marginal analysis of the additional transport costs (in terms of time and money) required if a road segment were no longer available represents the opportunity cost of that road. Combining this with the input costs of the road, we propose:

$$Productivity\ relative\ to\ second\ best\ route = \frac{Cost\ of\ moving\ to\ second\ best\ route}{total\ road\ input\ costs}$$

The productivity indicators developed in this research can be implemented over time, although work to further develop the indicators could begin in the short term, for example, by collating required data or applying the methods to a broader range of case studies in other parts of New Zealand. The indicators remain at an experimental stage of development and further research would be valuable for further developing the measures and guiding their implementation in the ONRC.

Abstract

This research project develops measurable criteria for the economic value of the movement of people and goods for use in the One Network Road Classification and contributes to the development of a performance measurement framework. The research focused on improving the measurement of the overall movements on a road, by supplementing vehicle counts with public transport patronage data, which contributes to the understanding of the total overall use of a road and the output roads support.

The research also explored productivity indicators for roads, based on the output roads support and the input costs of roads. We develop four indicators on this basis:

- public transport productivity indicator
- total passenger productivity indicator
- commute productivity indicator
- freight productivity indicator.

Our research specifically considers costs to generate estimates of the productivity of roads, which enables stronger correlation with performance measures. Finally, we explore the second best route productivity indicator. The opportunity cost of a road is considered by a marginal analysis of transport costs if the next best alternative road is instead used. The second best route productivity indicator is the most promising avenue to estimate the absolute productivity of a road, which could be refined and further developed for performance management purposes.

1 Introduction

1.1 Key research question/project objectives

This research project aimed to develop criteria for measuring the economic value of the movement of people and goods to inform the One Network Road Classification (ONRC) recently developed for New Zealand roads. The criteria identified by this research were designed to inform:

- the classification of different roads within the ONRC hierarchy of road types
- the performance measures framework that allows for ongoing measurement of the performance of different roads against defined standards.

The ONRC, as currently developed, uses established criteria for assisting in the classification and performance measurement of roads. The criteria are broadly based on traffic volume measures, which mean that the criteria are easy to use and apply for classification purposes. However, these existing criteria are seen as imperfect proxies for enabling comparison of the relative economic value and performance of different roads.

This research sought to explore improved and new measurable criteria that would allow for comparison of the economic value of the movement of goods and people on roads. The project specification stated the knowledge gap to be addressed in the research as follows:

The current ONRC performance measures for mobility are considered surrogates for network productivity and efficiency, due to the lack of measurable criteria for the economic value of the movement of people and goods. As examples:

- a bus is currently valued similarly to a car, yet may be moving over 40 more people
- traffic volumes on key arterials may be reducing, yet, due to dedicated public transport lanes, the total number of people movements, therefore the productivity/efficiency of the network, is increasing
- empty truck movements are currently valued the same as full truck movements (NZ Transport Agency 2014, p11).

Current criteria used for classifying and measuring the performance of roads within the ONRC system are based primarily on traffic volume measures. While these measures are readily available and do provide information on the relative density of use of different roads, they do not provide accurate measures of the economic value of the movement of people and goods. The project specification stated:

> *Annual average daily traffic (AADT) and HCV are proxies for economic productivity, while buses and active modes are proxies for density of exchange place function. Although these criteria provide a useful indication of economic productivity or density of exchange for the purpose of classification, they do not provide accurate measures of the economic value of the movement of people and goods. Such measures, rather than measuring numbers of cars, trucks and buses in particular, would help contribute to more efficient network management and through this, greater economic productivity.*

The research aimed to develop nationally measureable criteria for the economic value of the movement of people and goods for use in the ONRC, and to contribute to the development of the National Operating Framework performance measures. (NZ Transport Agency 2014, p11).

This report provides a summary of the findings of investigations into potential alternative measures of the economic value of New Zealand roads. It focuses both on measures that can assist in initial classification of roads across the existing network, and measures that can assist in ongoing monitoring of the performance of roads against standards defined by the ONRC. It presents short-term recommendations for improvements for use in conjunction with the current ONRC functional classification criteria, in addition to recommendations for longer-term, more fundamental revisions to criteria and performance measures.

This report also provides draft implementation guidance on how the indicators could be integrated with the ONRC. We expect this guidance will be updated and finalised when the indicators are also finalised. The draft implementation guidance is provided to show how the productivity indicators can be used to rank roads *within* current ONRC categories (eg within the regional road category or within the primary collector road category).

The research has found that a key challenge in identifying alternative measures is in developing indicators that can be practically and widely adopted, given existing data limitations. Trade-offs are necessary between indicators that provide new and accurate information about the economic value of roads, against those that are easily calculable and feasible to implement, given constraints on data and analytical effort. This report focuses on measures that are reasonably practical and cost effective to implement.

1.2 Structure of this report

- Chapter 2 outlines the economic concepts relevant to this assessment
- Chapter 3 outlines the types of measures currently used for informing the ONRC. These set the context for the framework we develop in chapter 4.
- Chapter 4 presents the methods employed to provide a better estimate of the value supported by a road.
- Chapter 5 contains the case studies, which apply the methods outlined in chapter 4.
- Chapter 6 provides guidance on the implementation of the recommendations arising from the research.
- Chapter 7 sets out our conclusions.
- Chapter 8 presents our recommendations, in the short and long term, to improve the understanding of the road's contribution to supporting economic activity and application to the ONRC. It also outlines areas for future research which will support the development of the ONRC, an understanding of the functional classification, and its application to network management.

2 Conceptual framework: measuring the value of roads for moving people and goods

This section outlines concepts relevant to the measurement of the value of roads in moving people and freight. We distinguish between three types of measures that are relevant to understanding a road's value:

- output measures
- input measures
- productivity measures.

Output measures are most important for classifying the relative importance of different roads for economic activity within the ONRC framework. Output measures provide information about the relative contribution of roads to economic activity. Input and productivity measures are more important for benchmarking the performance of roads within different classifications and their efficiency in achieving outcomes. Input measures provide information about the cost of different roads, while productivity measures improve understanding of the resource efficiency of different roads in providing outputs, in relation to levels of inputs.

This chapter discusses issues related to the accurate measurement of outputs, inputs and productivity for different roads across a network. It highlights particular challenges in measuring the economic outputs arising from roads, and suggests that relative (rather than absolute) output indicators are likely to be most feasibly developed.

2.1 Measuring the outputs of roads

Roads are commonly understood to provide the following types of benefits, which can contribute to economic value or a road's economic output:

- movements of people (or accessibility) – measured based on consumer/producer surplus arising from use of roads
- movements of goods (or accessibility) – measured based on consumer/producer surplus arising from use of roads
- agglomeration economies and other wider economic benefits (imperfect competition, tax wedge, etc) arising from imperfections in secondary markets
- place value/external amenity – ie direct or indirect consumption benefits associated with streets.

Existing cost-benefit analysis (CBA) frameworks for road infrastructure (for example, the *Economic evaluation manual* (EEM) (NZ Transport Agency 2013b) provide techniques for measuring these various types of benefits or outputs from roads. However, CBA is generally used to measure the value from incremental improvements to roads, rather than the outputs provided from the existing network.

In measuring the economic value of different links across the existing network, a key challenge lies in the economic role of roads as providing a complementary input (rather than standalone output) to economic activities including firm production and household consumption. In the absence of efficient road pricing, there are considerable difficulties in measuring the marginal contribution of a road's input to economic activity or economic welfare in the context of other inputs. The following sub-sections discuss challenges for measuring the output of roads, with reference to their economic function.

2.1.1 Road output as an input to economic activity

A road does not produce economic output by itself. The initial construction of roads has a positive impact on regional and national contribution to value-added, ie gross domestic product, but this effect is largely one-off and constrained to the period of construction. However, a road plays a part in supporting on-going economic activity and can be seen as a complementary input to economic activity. This is illustrated by the following hypothetical examples:

- A manufacturing firm may rely upon roads to transport intermediate inputs to their plant and to ship finished products out to customers. However, its actual production depends more upon the amount of labour and capital available to it, as well as general market conditions.
- A business services firm may rely upon roads to travel to meetings with customers. However, the production activities principally depend upon the labour and capital available to them, including skills and information, as well as general market conditions.
- A household may use a road to access consumption opportunities, or as a space to consume or undertake leisure activities. However, their activities will also depend upon other factors such as their income, free time and availability of consumption opportunities at the end of the road.

While these examples illustrate that roads facilitate a range of economic activities, the road is not solely responsible for the economic activity. Other inputs are also required.

In the context of the role of roads in moving freight, the value of other inputs to production generally outweighs the value of freight services by a considerable margin. This is illustrated in table 2.1, which shows the share of gross output[1] in six high-level industries that consists of purchases from the transport, postal and warehousing industry. The value of inputs from the transport and logistics sector ranges from a high of over 7% for freight-intensive sectors like forestry and logging and wholesale trade to a low of less than 2% for skills-based service industries.

This suggests that the marginal contribution of a particular road link to economic production is likely to be considerably less than the full value of freight moved on the road. This will also be the case for the road's role in moving people, and the marginal contribution that this has to facilitating, for example, human-capital intensive production (eg advanced producer services) involving labour coordinated at a single location through commuting trips.

Table 2.1 Share of industry gross output consisting of purchases from the transport, postal and warehousing industry, 2011

Selected high- level industry	Share of gross output consisting of purchases from the transport, postal and warehousing industry[2]
Forestry and logging	7.9%
Meat and meat product manufacturing	4.1%
Dairy product manufacturing	3.7%
Wholesale trade	7.0%
Finance	1.7%
Professional, scientific and technical services	1.9%
Total all industries	2.9%

Source: Insight Economics (2014)

[1] Gross output measures the total value of all sales in a given industry.

[2] ANZSIC06 industry I, transport, postal and warehousing

While the presence of the road may enable labour and capital to be employed productively in a particular location, the productivity of those inputs will not necessarily drop to zero in the absence of the road[3]. This is because firms tend to have alternative options for responding to the availability of road infrastructure. For example, firms could re-route freight along parallel infrastructure such as other road links, rail or sea links. Alternatively, firms could also relocate production facilities, meaning production continues, even in the absence of a particular road link.

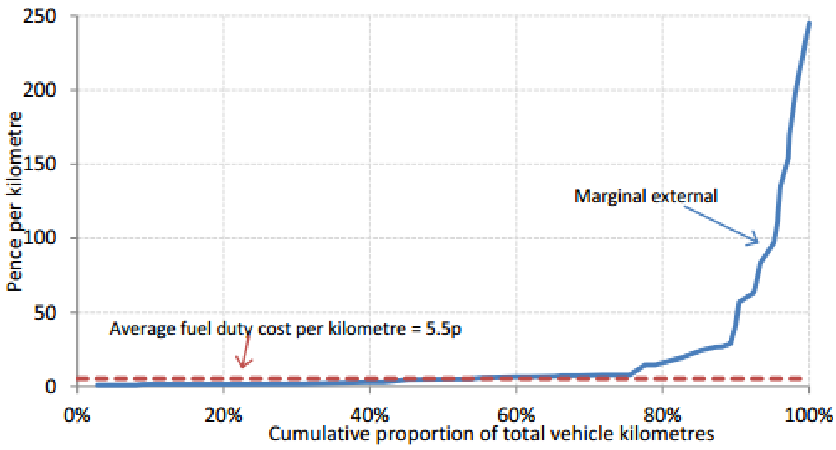
Both of these options would increase costs for the plant by increasing their supply chain costs or requiring it to locate in a less productive location. However, it is likely that goods will still be produced even in the absence of any particular road. This, again, poses challenges for measuring the contribution of any individual road to economic productivity.

2.1.2 Lack of efficient pricing creates measurement challenges

Microeconomic theory suggests that in a competitive market, the marginal contribution of any individual input to production can be measured by the price it commands in the market. This principle is employed by statistical agencies when calculating the output and productivity of firms, industries and entire economies.

For example, consider a case in which a firm purchases $100 of raw materials that it subsequently transforms into finished goods worth $500. The marginal contribution of the raw materials to the firm's production would be equal to their purchase price of $100. However, we cannot apply this principle to value the output of road networks, as roads are not directly priced. The most direct price (eg the price of fuel) does not capture the full cost of using the road (eg congestion externalities). Road users pay for the provision and use of roads indirectly, through fuel taxes, road user charges, public transport fares and local government rates. However, this pricing is not efficient as it does not typically reflect the intensity of demand on roads. This is illustrated in figure 2.1, showing the gap between the marginal external cost of driving (ie congestion externalities) in the UK and fuel taxes collected. Auckland-specific estimates of congestion externalities are available in Wallis and Lupton (2013).

Figure 2.1 Distribution of the marginal external cost of driving in the UK



Source: Johnson et al 2012

[3] Following The Treasury (2005), we argue that in an economy with full employment, labour and capital would be re-used for another purpose.

In the presence of unpriced congestion externalities, access to road networks is rationed by queues rather than by prices (Duranton and Turner 2011). It may not therefore be the case that the busiest roads are carrying the most valuable traffic. In fact, busier roads may in fact be serving lower-value trips on average, as people and goods with a higher value of time may have chosen to avoid them.

One solution to this, of course, would be to implement congestion pricing or demand-responsive road tolls. In addition to encouraging more efficient use of road networks, this would provide us with good data on which roads were most valuable to freight and people movements. All else being equal, we would expect more people to be willing to pay more to travel on roads that offered them better production or consumption opportunities.

However, implementing congestion pricing is not within the scope of this study. Consequently, it will be necessary to look for indirect measures of roads' marginal productivity, ie surrogate markets in which people can reveal the value they place upon roads. These could include, for example, individual transport markets, labour markets, goods markets or housing/land markets.

2.1.3 Transport infrastructure links to economic welfare are indirect

A further way of understanding the indirect links between road infrastructure and economic value is to consider the indirect ways by which roads contribute to economic welfare. In the same way that measuring the economic value of roads' contribution to a firm's production process is difficult, measuring the contribution to a wider concept of economic welfare is also challenging.

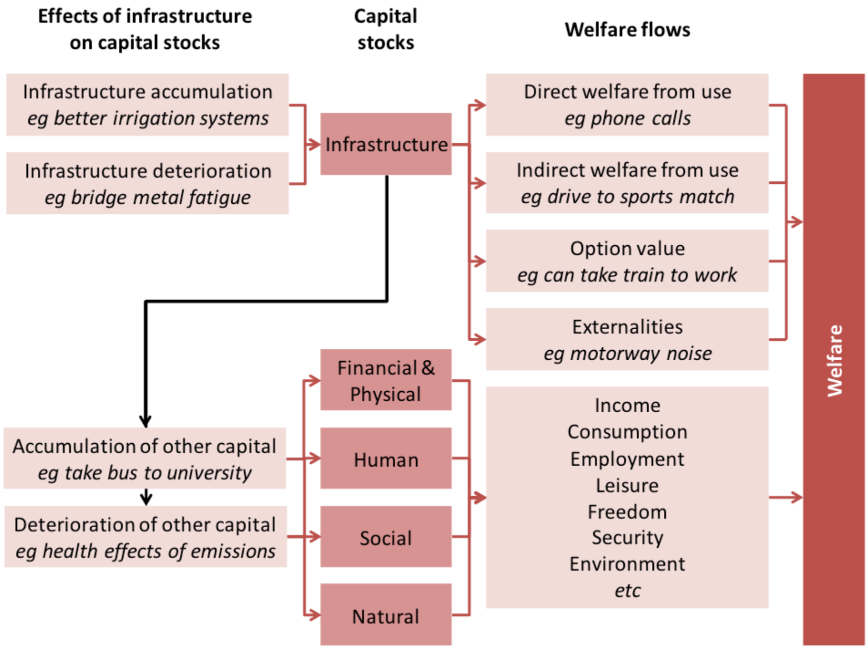
In developing an infrastructure performance indicator framework for the New Zealand Treasury's National Infrastructure Unit, Schiff et al (2013) note that:

> *the relationship between transport and welfare is largely indirect, in that transport facilitates other activities that generate welfare. Transport therefore generates more welfare if it facilitates activities more efficiently, more safely, and at lower cost* (p32).

This indirect relationship between transport infrastructure and economic welfare is important when considering appropriate indicators for the sector. The immediately measurable transport output of road infrastructure (traffic activity) is not important in itself for creating economic value, but rather transport activity is an input into welfare-creating consumption or production activities.

Schiff et al (2013) illustrate the indirect relationships between infrastructure and economic welfare in their diagram reproduced in figure 2.2. While referencing infrastructure more generally, rather than road transport infrastructure specifically, the links between infrastructure capital stock, other forms of financial, human, social and natural capital and final impacts on welfare flows are relevant to this discussion.

Figure 2.2 Model of the links between infrastructure and economic welfare



Source: Schiff et al (2013, p18)

Road infrastructure and the freight and passenger transport enabled by it can facilitate both accumulation and deterioration of various types of capital stocks, and can contribute to positive and negative welfare flows. Road infrastructure can enable access to consumption activities or production inputs, can have option value by allowing potential for certain activities and can produce negative welfare flows in the form of externalities such as noise, carbon emissions or air pollution.

An implication from these complex relationships between infrastructure, the transport activity facilitated by the infrastructure and the final impacts on economic welfare is that high traffic volumes may not necessarily equate with high economic value from a road. In some cases, lower traffic volumes may indicate higher overall welfare outcomes if transport inputs are more efficiently contributing to economic outputs. Schiff et al (2013) note that:

> *volume indicators such as kilometres travelled are not in themselves a good guide to social benefits. Desirably, the best indicators will reflect how well the transport infrastructure provides destination and mode choices, and limits the distance and time required for travel* (p30).

Given that transport activity is an input into economic activity rather than a final economic output, ideal indicators of the relative economic contribution of roads will point toward the level of economic opportunity, potential or activity enabled by transport networks.

2.1.4 Measuring road's economic output across geographic scales

Measures of the value of transport infrastructure are commonly undertaken across three scales; the national level (macro), regional level (meso) or local level (micro). We borrow this geographically based classification from Banister and Berechman's (2001) review of the links between transport investment and economic development. We consider this a useful framework for investigating potential enhancements to ONRC indicators as these three levels reflect:

- the scales at which economic, government and social activities are commonly organised
- common ways in which transport and economic data and modelling tools are organised and reported.

In our assessment we consider that:

- A national level analysis of the relationship between infrastructure investment and national output (ie GDP) is not useful to determine the value it supports. The aggregate value of investment is too high level to classify or measure the value of individual roads. The overall performance of the network will bear a relationship to economic activity but pinpointing the impact contributed by a single road is not possible.
- A regional level analysis between roads and regional output is also too high level to determine the value roads support. The literature on the relationship between transport infrastructure and economic activity at a regional level is concentrated on the impact on accessibility, job density and labour productivity (ie agglomeration impacts). This is not useful for classifying or measuring the value of individual roads.
- A local level analysis is most useful within the ONRC context, for road classification purposes. Unlike analysis at a national or meso level, local level analysis enables the relationship between a road, rather than a network, and economic activity to be determined.

Further details on the scale of analysis and key literature are included in appendix F.

2.1.5 Measuring the place function of roads alongside their movement functions

In urban areas, roads can contribute to economic welfare not only through their function of facilitating vehicle movement, but also through their functions in enabling pedestrian access to buildings and land uses adjacent to roads and in providing spaces within the road corridor itself for economic and social exchange and consumption opportunities (Jones et al 2007). While the focus of this research will be on improving measurement of roads' movement or link function, an integrated understanding of both place and movement functions is critical for a more complete knowledge about the overall contribution of roads to economic welfare.

Gehl (2003) refers to three historical functions of public street space in urban areas: as meeting spaces for social exchange, market spaces for trade and connection/traffic space for access. Movement and place functions overlap to some extent with pedestrians often using streets simultaneously as movement corridors and places of social and economic exchange. The place function of roads has historically been overlooked during the establishment of recent road investment and planning frameworks, with a recent report from UN-Habitat stating:

> *there are multiple functions of streets as links or places that have commercial, economic, civic, ceremonial, political, cultural and social value. However, this multi-functionality is often overlooked, and streets are usually regarded as mere links in a road network, enabling travel between two or more destinations.* (UN-Habitat 2013, p2)

Recently, transport policy and road planning regimes have moved toward consideration of the multiple functions of streets under the banners of 'complete streets', 'liveable streets' and 'streets for all' (UN-Habitat 2013, p30).

Consideration of a road's place function is primarily significant in urban areas, and most important in dense nodes of economic activity such as downtown or neighbourhood centres. The place function of roads can contribute to economic welfare by providing good micro-scale connectivity and environments conducive to service-based economic activity. Cervero (2009) argues that:

> *with knowledge- and service-based industries driving economic growth in many sectors of the modern economy, creating functional yet livable cities is essential to global competitiveness. Historically, transport infrastructure has been designed principally to enhance mobility, including labor inputs and manufacturing outputs. However, large-scale infrastructure such as limited-access elevated freeways often carry with them high environmental costs, notably air and noise pollution, land consumption, and urban dislocation. To achieve the kinds of high quality of life and public amenities needed to attract and retain high-skilled, knowledge-based workers, more and more cities are seeking to strike an appropriate balance between transport infrastructure as an economic conduit and broader place-making and community-building objectives.* (p211)

Cervero suggests that the productivity premium arising from successful places (not just successful transport movement systems) may be best reflected in land rents. A developing literature provides evidence of links between the place performance and economic benefits of urban streets (Sohn et al 2012; Pivo and Fisher 2011; the New York City Department of Transport 2013; SGS Economics and Planning 2014).

Ideal indicators of a road's place function would measure the importance of the road corridor itself as a place of economic and social exchange and the economic and social significance of immediately adjacent land-uses and buildings. Burdett et al (2015) identify a set of potential indicators for place functions including:

- land-use measures (eg residential population density or commercial job density)
- people characteristics of place users (eg age)
- activity measures (eg dwell times of pedestrians).

Other potential indicators could include property value measures as a proxy for the intensity of adjacent land uses for economic activity, indicators of the area of road corridor devoted to public space or pavement or indicators of pedestrian accessibility.

2.1.6 Relative output measures are most promising for measuring outputs

Due to challenges in accurately measuring the contribution of any particular road link to economic activity or welfare, relative measures rather than absolute measures are likely to offer the most promising opportunities for improved understanding of a road's value or output. Relative measures attempt not to assess the absolute level of economic value created by a particular road, but rather place the economic value of individual roads in a relative or comparative perspective.

Relative indicators of economic output can be used to determine which transport links or transport networks are likely to contribute more to economic output. They offer an approximate means of comparing the output from different roads (and other transport links) and identifying if the output associated with roads has changed over time. For example, currently used output measures within the ONRC that are based on traffic volume, are relative rather than absolute measures. Traffic volume does not provide a direct estimate of a road's contribution to economic activity. However, comparison of traffic levels across roads can provide information about the relative economic importance of different links.

Econometric techniques that analyse the contribution transport networks make to firm production functions and/or household consumption functions by modelling the relationship between transport infrastructure variables and measures of economic outcomes. However, the data required for such modelling is typically only available in aggregated format at a national level. Data on economic output (eg GDP) and private sector capital formation is generally only available at a national level or, in some countries, at a regional or state level[4]. While some economic data, such as employment data, is available at a small area unit level, this does not provide a complete measure of economic activity as labour is an input to production rather than an output from it.

These data limitations constrain the ability to measure the absolute value of output associated with transport networks at a detailed geographic level. This means it is difficult to compare the output of different road links within a network, although it may be more possible to understand the value of the network as a whole (for example, at a national scale).

Consequently, relative indicators are likely to offer the most potential for improved output measures for roads. Relative indicators (eg traffic volumes, proximity to hospitals and other locations) are often available at a detailed or micro geographic scale, allowing for comparison of value across different links and corridor segments within a road network.

2.2 Measuring road inputs

Transport networks are **complementary** to other activities rather than a means in and of themselves. In the previous section, we identified some implications for measuring the absolute or relative value of outputs from transport networks. However, this also has implications for the measurement or categorisation of input costs.

Small and Verhoef (2007, pp97–105) observe that the costs of transport include a mix of a) short-term fixed and variable costs and b) private and social costs. In other words:

- Some of the costs of providing transport networks, such as the cost of providing road corridors, are fixed in the short term regardless of the level of use. For example, it costs the same to construct a two-lane road that carries 1,000 vehicles per day as it does to construct a two-lane road that carries 5,000 vehicles per day.
- Some of the costs of providing or accessing transport networks scale with the level of use. For example, the more vehicles there are on a road, the higher user costs such as vehicle operating costs and travel time costs will be. Similarly, higher levels of use may also lead to higher social costs, such as crashes and unpriced environmental externalities such as vehicle noise and emissions.

In addition, we note that governments directly provide (or procure) transport services on some transport corridors. In particular, regional councils are responsible for managing public transport (PT) services in urban areas. Users pay some, but not all, of the costs of operating PT services through fares.

In order to account for the cost of inputs to transport networks, we have adapted Small and Verhoef's (2007) categorisation slightly, as shown in table 2.2. While we have maintained their high-level distinctions between fixed and variable costs and private and social costs, we have included additional detail on two issues. First, we have included public transport operating costs, as well as vehicle operating costs, as public transport is an important component of urban transport networks.

Second, we have disaggregated fixed transport corridor costs into three components: capex (construction and renewal) costs, opex (maintenance and public transport operation) costs, and land costs. Although

[4] Statistics New Zealand now publishes an annual regional GDP series. However, this data series only covers the years 2007–2014, which makes it difficult to implement the time series modelling approaches employed in the economic literature.

land costs are not included in central government's financial valuations of the road network (or rail network), land used for transport corridors is nonetheless associated with a social opportunity cost[5]. In other words, increasing the amount of land devoted to transport reduces opportunities for other land-users, such as households and businesses, to use that land for other purposes[6].

Importantly, we have adapted Small and Verhoef's (2007) inclusion of private and social costs. This provides an overall perspective of the costs of roads.

Table 2.2 also proposes sources or methodologies for calculating or estimating these input costs. We find it is possible to calculate most or all input costs based on existing data, plus some additional geospatial analysis.

Table 2.2 illustrates that obtaining input costs at local scales is often easier than measuring road outputs. In contrast to output costs, input costs are generally more easily defined and attributable to a particular road segment. This makes it possible to understand input costs in an absolute, rather than relative sense.

It should be noted, however, that there remain limitations to attributing input costs at the micro-scale. For example, in allocating the total capital cost of an urban motorway among short segments, it may not be entirely accurate to average the total build cost on a per kilometre basis. At this micro-scale, differences in factors such as expected axle weight or load, ground conditions, structures and treatment of utilities along the motorway route may mean substantial variations in capital costs across different segments. Nevertheless, attributing costs at this scale is probably simpler than attributing benefits. In addition, gathering information on micro-level capital costs is likely to require prohibitively expensive and time-consuming data collation and analysis.

Table 2.2 Categorising inputs to transport networks

Type of cost	Potential source/method for measurement
Variable costs	
Costs borne mainly by users	
Vehicle capital expenditures	Can be inferred from census car ownership data at area unit level.
Vehicle operating costs	Can be inferred from traffic count data plus standard (EEM) factors for vehicle operating costs (eg fuel and road user charges).
Parking costs	Parking costs are often not borne directly by users, due to the fact that parking provision is regulated to ensure an oversupply of free parking. See Shoup (2005) for a general explanation of the market/pricing distortions arising from parking regulations and MRCagney (2013) for some relevant empirical evidence in the Auckland context. In areas where on-street parking is metered (priced), district council data (eg Auckland Transport (AT) data) can be used to value parking costs. In other areas, this is not possible.

[5] See pp22–23 of The Treasury (2015) for a discussion of the concept of opportunity cost. While their discussion refers to labour inputs, rather than land inputs, it is nonetheless relevant for our purposes here.

[6] We note that there is an endogeneity issue here – as discussed in the previous section, transport networks can in fact support surrounding land uses, and higher neighbouring land values, by providing accessibility. They can also lower nearby land values as a result of negative environmental externalities associated with vehicle operation. In other words, the value of nearby land is likely to be significantly different if a transport link did not exist. Consequently, we suggest that this is best seen as a measure of the marginal cost associated with incremental changes to the size of the transport corridor. Marginal changes such as widening or narrowing an intersection or adding a passing lane are unlikely to have a major impact on surrounding land values.

Type of cost	**Potential source/method for measurement**
Variable costs	
Public transport fares	Can be estimated for individual corridors using public transport operator or agency fare data. In Auckland, AT HOP data can be used to calculate fares paid.
Travel time	Can be inferred from traffic count data, plus actual or estimated vehicle speeds and standard (EEM) factors for the value of time.
Schedule delay and unreliability	Difficult to account for without detailed data on variability in road speeds.
Costs borne substantially by non-users	
Crash costs	The NZ Transport Agency's Crash Analysis System (CAS) data can be matched to individual roads or road segments. The average cost of accidents can be estimated using standard (EEM) factors for the cost of injury or death crashes. Rail accident data is held and occasionally published by KiwiRail.
Government services	This category includes, eg the costs of road policing and safety campaigns. These expenditures can be measured at the national or regional level and allocated to individual roads on the basis of their size or traffic flows.
Environmental externalities:	
Particulate matter (PM) emissions	PM emissions account for the majority of health costs from air pollution. In New Zealand's urban areas, vehicle operation and domestic heating are the main (anthropogenic) contributors to poor air quality. The Health and Air Pollution in New Zealand (HAPINZ) model estimates the health costs of poor air quality at an area unit level throughout New Zealand. It can be used to analyse the health impacts of roads in particular areas.
Greenhouse gas emissions	Can be inferred from traffic count data plus standard (EEM) factors for greenhouse gas emissions from vehicle operation.
Noise externalities	The EEM specifies procedures for valuing noise impacts but they are difficult to implement without considerable data collection. PwC and MRCagney have previously developed tools for estimating noise impacts from bus operation on selected corridors based on the General Transit Feed Specification (GTFS) data on bus volumes on selected roads and transport agency data on the composition of urban bus fleets.
Fixed costs of providing corridors:	
Opportunity cost of land	GIS analysis using Land Information New Zealand (LINZ) road centreline data and OpenStreetMap data can be used to identify the width of road corridors and other transport corridors. Once the physical footprint of roads has been identified, property sales data or ratings valuations data (available for Auckland) can be used to estimate the current value of this land.
Capex (construction and renewal) costs	GIS analysis can be used to identify the size (width) and type (eg state highway or local road) of roads. The overall capital value of these roads can then be estimated by allocating out national- or regional-level estimates of the book value of roading assets. A similar approach can be applied to the rail network. In principle, this approach should provide a reasonable indication of the current (depreciated) value of roads. An alternative approach would be to calculate (on the basis of construction cost planning rates or recent project costs) the cost to replace roads.
Opex (maintenance) costs	Data on total road maintenance costs at a regional level or district council level over a multi-year period can be allocated out to individual roads based on data on road size and type.

Type of cost	Potential source/method for measurement
Variable costs	
Public transport operating subsidies	GTFS data can be used to identify the quantity of public transport service operating on individual transport corridors. MRCagney has developed the TransitFlow tool for undertaking this analysis. GTFS data can be used to estimate the operating or contracting costs of buses running on individual corridors (eg based on cost planning rates or overall network operating costs). In order to avoid double counting public transport costs, fares paid would have to be subtracted from PT operating costs.

2.3 Measuring the productivity of roads

In addition to measuring the outputs and inputs of roads, we can also measure the relationship between outputs and inputs by using productivity indicators. Output measures by themselves may be useful for understanding the relative economic importance of various links across a road network. Likewise, input measures by themselves may be useful for understanding the relative cost of providing and maintaining various links. However, productivity measures that bring both input and output measures together, can provide useful information about the relative performance of different road links within a network. Within the context of the ONRC, these productivity measures may be useful for performance management, enabling benchmarking of road efficiency across road controlling authorities (RCAs) and different geographic locations.

In defining productivity measures for roads, we draw a loose analogy with measures of economic productivity. According to the OECD (2001), productivity is 'commonly defined as a ratio of a volume measure of output to a volume measure of input use'. In algebraic notation, this can be written as:

$$Productivity = \frac{Outputs}{Inputs}$$

There is not necessarily any single measure of productivity nor a best measure of productivity. For example, productivity for an industry or the economy as a whole can be measured as the ratio of economic output to labour input (labour productivity), the ratio of output to capital input (capital productivity), or the ratio of output to capital and labour inputs (multifactor productivity). The appropriateness of different measures depends upon the data that is available and the aim of the analysis[7].

A related concept is productivity growth, which reflects the change in the ratio of outputs to inputs. Hazledine et al (2013) notes that productivity can be increased by:

- increasing the quantity of output while holding the quantity of inputs constant
- reducing the quantity of input required to produce a fixed amount of output.

According to OECD (2001), the objectives of productivity measurement include:

[7] However, in saying this, we note that there are some conceptual limitations to the use of productivity as a performance measurement tool. While our description of productivity is aligned with concepts of economic efficiency – ie maximising the outputs generated per unit input will tend to encourage greater allocative efficiency – productivity does not measure the effectiveness of spending. We note that productivity is not the only measure which could be used for performance management and that a range of indicators will provide a more comprehensive picture of the performance of a road and network.

- understanding the impact of **technological** change on the economy, or a sector of the economy
- identifying how **efficient** or **cost-effective** existing production arrangements are, or how their efficiency is changing
- **benchmarking production processes** or other economic activities against each other to understand their relative productivity
- measuring **living standards**.

In our view, the second and third objectives (measuring efficiency[8] and benchmarking processes) appear to be most relevant to the case of the ONRC. In doing so, we propose to define a set of input and output measures and compare them to examine the relative productivity of roads.

The question is therefore whether there is a need to further elaborate and better explain as to how possible outcomes from this approach could be interpreted especially in light of the aim of the study to **inform** how roads are classified within the context of the ONRC (NZ Transport Agency 2014).

[8] The efficiency of a transport network is a separate concept of efficiency. The efficiency of a transport network relates to the performance in terms of moving people and goods. Different measures are used eg maximising vehicle flow, minimising travel time for this purpose. The performance of a network can also refer to the accessibility of an area, (eg number of people within X minutes or X km of transport options).

3 Existing measures for the value of roads used for the ONRC

This section outlines the types of measures currently used for informing the ONRC. Various indicators are used for the purposes of classifying roads within the ONRC hierarchy, and for measuring the performance or efficiency of roads in meeting defined standards for each road category.

The previous section discussed some first principles considerations for measuring the value of roads. In this section, we look at how measures are currently being used in practice, and assess the extent to which existing measures adequately capture different roads' contributions to economic productivity. This section is organised as follows:

- A brief summary of the purpose of the ONRC.
- A summary of existing measures used to inform classification and performance management within the ONRC.
- An assessment of the extent to which existing ONRC measures enable good comparison of economic value, and performance across segments of the network.

3.1 Purpose of the ONRC

The ONRC has been developed for use by RCAs for the purposes of supporting:

- value for money and consistency in asset management and investment decision-making across RCAs throughout the country
- provision of a consistent customer experience for road users across the country: 'over time, road users can increasingly expect to have similar experiences across the country, on roads in the same category' (NZ Transport Agency 2013, p4).

The ONRC has been developed by the Road Efficiency Group, a joint local government and the New Zealand Transport Agency (Transport Agency) initiative.

In the past, RCAs have tended to take local approaches to develop and maintain roads within their jurisdiction, based on local needs and affordability. This means that maintenance of roads, and the associated level of service for users, can be tailored for local requirements as needs and financial constraints allow. However, there is not a great deal of consistency between RCAs and the variation in the service level for users can be pronounced as they travel across local government boundaries.

The ONRC aims to provide a nationally consistent framework that is at the same time guided and informed by the local and regional context. It is intended to be used by territorial and local authorities (TLAs), the Department of Conservation, the Waitangi National Trust, the Ministry of Transport and the Transport Agency, in their role as RCAs. In particular, use of the ONRC will:

- support more consistent asset management across New Zealand
- contribute to journey safety and consistency improving the user experience over time
- contribute to a more efficient and safer network by making it easier for organisations, responsible for planning, delivering, operating and maintaining the road network, to collaborate and prioritise their capital programmes.

The ONRC categorises New Zealand roads according to their function within the national road network. The classification framework specifies three components that can be applied to all New Zealand roads. The three components, which are applied sequentially, are:

- a functional classification
- defined customer levels of service for each road category
- performance measures.

The ONRC is currently under development and not all components of the framework have been confirmed. The functional classification was confirmed in December 2013, while the customer levels of service remain provisional and the performance measures are under discussion (NZ Transport Agency 2015a).

3.2 Measures used for functional classification

The functional classification involves six road categories that are determined by reference to various criteria such as measures of average daily vehicle traffic, the size of the towns and cities the roads link, and the importance of key locations that the roads serve such as airports, sea ports, hospitals or tourism sites. The criteria reflect economic and social dimensions, recognising the economic and place functions of roads. The six categories, listed in order of importance are:

1. national
2. regional
3. arterial
4. primary collector
5. secondary collector
6. access.

The classification system depends heavily on vehicle volume measures. It also uses data on the population of towns and cities that are linked to enable categorisation. These are both factors where data is readily available. The criteria and thresholds for categorising roads are understood as ‘a mix of proxies for measuring roads’ economic growth and productivity contribution, their social contribution and their link and place functions’ (NZ Transport Agency 2013a, p7).

3.3 Measures used for performance management

The ONRC also includes performance measures and targets which provide a framework for measuring progress toward desired outcomes, including customer levels of service outcomes defined for each category of road.

Performance measures remain provisional at this stage and are specified in draft form in the performance measures framework (NZ Transport Agency 2015b). The measures are defined across six customer levels of service variables:

- travel time reliability
- resilience
- optimal speed
- safety

- amenity
- accessibility.

Expected outcomes are defined for each of these variables using a number of indicators measuring performance with regard to:

- customer outcome
- technical output
- cost efficiency.

Cost-efficiency performance measures attempt to measure the efficiency of achieving the various customer level of service outcomes. Asset management measures are defined which measure the quantity of work undertaken. For example:

- pavement rehabilitation quantity (lane km and m^2)
- all significant (by cost) work categories
- average life achieved of pavement.

Comparing these asset input costs against achievement of outcomes allows for a preliminary understanding of the efficiency, or productivity of different roads.

3.4 Assessment of current measures

3.4.1 Output measures

Current measures used for functional classification purposes largely rely on output measures (rather than also considering input or productivity measures). Roads are measured for their relative economic importance by using output indicators such as traffic volume counts and the population size of the cities connected by the road.

The ONRC's functional classification relies heavily on traffic volume indicators as proxies for the relative economic importance of different roads. As highlighted in the previous section 2.1.3, there are various problems in using volume indicators as measures of the welfare contribution of roads. Nevertheless, there are also advantages outlined below.

Vehicle volume indicators have advantages in being widely available indicators with extensive data collection systems already in place for many New Zealand roads. Traffic volume indicators are also reasonably simple and clear to understand. When used in combination with the ONRC's 'location importance' indicators they would intuitively appear to provide a reasonable assessment of the relative importance of various road links. If a road is heavily used by many people and is connecting places of importance it seems intuitively reasonable to expect it to be supporting economic welfare, as people use the road to travel for productive purposes (eg commute to work) or leisure purposes.

Traffic volume measures are also widely used internationally for road network investment and planning purposes. Use of these indicators is also consistent with New Zealand's current frameworks for investment decision-making and economic evaluation of transport projects (eg as specified by the EEM). The most significant economic benefits of transport projects are generally calculated using indicators of traffic volume to derive travel time savings and vehicle operating cost reduction benefits.

However, while use of traffic volume indicators for investment planning purposes is well established, some caution should be applied in relying too heavily on these measures as proxies for the economic value of roads – and as the basis for classifying roads. Current use of vehicle volume indicators by the ONRC risks the following problems for road classification:

- Current traffic volume indicators measure vehicles and as a result are likely to underestimate the number of people moving in urban transport corridors, eg if there are a significant number of well-occupied buses.
- Traffic volume indicators do not provide a way of distinguishing between the different value generated by different types of freight or passenger movements. For example, a truck moving 40 tonnes of logs may be facilitating less economic value than a commercial van moving half a tonne of fresh seafood given the different commodity values of these goods. Likewise, a passenger trip for business purposes may contribute more to economic output than a passenger trip for leisure or social purposes.
- Current volume indicators may not account for differences in the relative value of roads associated with the availability of alternative road links or 'second best' transport options. For example, a road may be relatively lightly used, but may be more valuable than a more heavily used road because of the lack of alternative network links. This may be the case for lightly-used inter-regional links with limited alternative options, or for bridges and tunnel links that if removed require considerably longer travel times. In contrast, heavily used roads in dense urban areas where many alternative routes exist may have less value than implied by measuring their level of traffic alone. The current ONRC framework does, to some extent, account for these issues by including place importance criteria. For example, under the framework, a road can achieve a high classification for linking centres with high population, even if levels of traffic are relatively low.

3.4.2 Performance measurement indicators

Section 3.3 outlined the draft measures for performance management. These measures focus on moving people and goods between locations reliably, quickly and safety but appear under-developed with regard to resource efficiency or productivity indicators. There is some consideration given to economic productivity through the optimal travel speed component of the framework. This measure explicitly considers safety, (network) efficiency and economic productivity.

This is the only reference to economic productivity in the performance management framework. We consider that the draft measures underplay the relationship between the use of the road and generating economic output. Some trips will contribute to generating more to economic output than others, for example a trip by an electrician to a job will contribute more to regional or national value added than a 'Sunday drive', all else being equal. This is a limitation of the current draft performance measurement framework. Note that leisure trips are valuable and worthwhile, as they improve the welfare of the travellers. However, the impact on a national economy is smaller than a trip undertaken for production.

In addition, while some consideration is given to the most obvious input costs to roads (eg maintenance costs), no account is given of a wider range of social input costs such as capital costs, underlying land costs or public transport service provision costs.

3.5 Assessment of current place function measures

The ONRC system aims to account for both movement and place functions of roads in contributing to economic and social wellbeing. Alongside considerations of the movement function of roads, those that score highly on place indicators can contribute to higher levels of categorisation within the ONRC.

We observe streets around New Zealand and overseas which are pedestrianised or are shared spaces. The success of these areas suggests that as a destination in its own right, streets improve welfare. However, the measures in the ONRC to account for the place function can be considered under-developed.

Current indicators used to measure place functions include:

- bus volumes (numbers of vehicles or passengers)
- active modes (numbers of pedestrians and cyclists at peak times)
- seaports and inland ports (classified by freight tonnage or value)
- airports (classified by passenger numbers)
- tourism sites or routes
- hospitals (classified by tertiary or regional hospitals).

While these indicators aim to reflect the place functions of roads, in many cases they do not measure the types of social or market exchange and pedestrian access functions discussed in much of the literature, but rather help identify 'important locations' that are served by the movement function of road infrastructure. As noted by Burdett et al (2015) in their report on identifying place indicators for New Zealand state highways and arterial roads in urban contexts:

> *The definition of place function and performance in the ONRC is different from the way place is considered in this research. Within the ONRC, place refers in particular to important places and the way they are accessed. In particular connectivity for remote regions, critical routes, ports, airports, tourism destinations and hospitals. The ONRC does not have any clearly defined performance metrics for place function.* (Burdett et al 2015, p15)

The ONRC suggests that bus and active mode volume indicators can be used as 'proxies for density of "exchange" place functions' (NZ Transport Agency 2013a). While such indicators may roughly suggest road corridors with high place value (eg roads with high numbers of buses such as downtown arterials may also be important destinations and places of significant market and social exchange), bus and cyclist movement volume indicators are at best indirect measures of place and may be more appropriately understood as indicators of a road's movement function. Pedestrian indicators may be more suitable, as pedestrians can be using a road corridor both for movement purposes and for exchange. Although the ONRC indicators on port, airport, tourism and hospitals have value in reinforcing the identification of strategic links, they seem inappropriate as indicators of a road's place function.

Improved measures for place functions are not the focus of this report. Nevertheless, there appear to be considerable opportunities for clarifying the role of place function within the ONRC. Burdett et al (2015) identify a set of potential indicators for place functions including:

- land-use measures (eg residential population density or commercial job density)
- people characteristics of place users (eg age)
- activity measures (eg dwell times of pedestrians).

These types of indicators may contribute to an improved measurement framework for the ONRC that includes consideration of place function. We consider this topic requires a dedicated research stream and do not further investigate these types of improvements in the following section. Rather, our improvements focus on optimising existing indicators of the movement function of roads.

4 Potential improvements to ONRC measures

Our assessment of indicators currently in use by the ONRC for the purposes of classification and performance management of roads highlights a number of areas for refinement and improvement. This section outlines potential methods for improving the following types of measures:

- road output measures
- road input measures
- road productivity measures.

This chapter considers opportunities for improving ONRC measures, based on our evaluation of current measures in chapter 3, and consistency with our conceptual framework established in chapter 2. We focus on exploring new measures that can be practically and widely adopted, given data limitations and the need for cost-effective implementation. Our investigation of alternative measures highlighted trade-offs between indicators that provide new and accurate information about the economic value of roads and those that are easily calculable and feasible to implement given constraints on data and analytical effort.

This section briefly outlines a number of potential methods for improving measures. More detailed methodological material is included in appendices C to E.

4.1 Opportunities for improving output measures

Chapter 3 highlighted that within the current ONRC framework, road output measures (rather than input or productivity measures) are the primary measures used to inform the classification of roads. In our view, it is appropriate to continue using output measures for classifying roads into different categories.

The current ONRC makes use of a range of proxy output measures; however, there is acknowledgment that current measures are imperfect in representing the economic value provided by different road links. There is a heavy reliance on traffic volume measures as a proxy for economic importance. Key issues with the use of traffic volume measures include:

- potential for vehicle volume measures to not align with people volume or freight volume movement on a road link
- inability to distinguish between the purpose or relative value of trips measured by traffic volume measures
- inability to highlight the presence of alternative road links that may affect the value of a particular road segment.

Chapter 2 outlined a conceptual framework based on economic principles, suggesting that improved economic output measures for roads should attempt to capture the marginal contribution of roads in their contribution to economic activity or welfare. As the output of roads can be viewed as an input to economic activity, value measures should aim to capture the extent to which roads efficiently provide inputs to economic activity.

In section 4.1.1 we consider the available data that may be used to improve output measures. Based on the availability of the data, we outline four potential avenues for improving existing ONRC output measures:

- commute output indicator

- freight output indicator
- business-to-business output indicator
- ‘second best’/alternative route approach to measuring output.

The first three indicators seek to isolate particular trip purposes that make the most significant contributions to economic productivity (trips for commute, freight and business-to-business (B2B) interaction purposes). They establish indicators of the extent to which roads support these various trip purposes.

The final, second-best/alternative route indicator provides an indicator of the economic output of road segments that is better grounded in microeconomic reasoning. Comparing transport costs for existing traffic with or without the road provides a better measure of the net value that people obtain by being able to travel on the road, rather than divert to another, less convenient route.

4.1.1 Available data for improved output measures

Table 4.1 outlines a range of data that may be used for improved road output indicators. This includes both measures of road use (including public transport boardings and cycle and pedestrian counts, which could be incorporated to develop a more complete picture of people movements), and measures of economic value that may be connected to the presence of a road. Appendix A contains a more complete assessment of the availability of the indicators below. Appendix B contains a summary of our assessment of the comprehensiveness of AADT counts, one of the key current criteria in the ONRC functional classification.

Table 4.1 Road output measures: indicator variables currently available

Indicator	Geography	Source
Road use measures		
AADT – light vehicle counts	Local level – individual roads	NZ Transport Agency
AADT – heavy vehicle counts	Local level – individual roads	NZ Transport Agency
Rail freight movements	Regional / local level – inter-regional freight flows	MoT Freight Information Gathering System
Public transport boardings	Local level – individual services	AT HOP data (Auckland only)
	Regional level	MoT transport indicators
Cycle counts	Local level – selected cycle routes	AT cycle count data (Auckland only); counters in other regions
Pedestrian counts	Local level – selected streets	Heart of the city pedestrian counts (Auckland city centre only); counters in other locations
Commuting flows (by mode of travel)	Local level – flows between individual area units	Statistics NZ – 2013 Census data (held by MRCagney)
Vehicle kilometres travelled (vkt)	Regional level	MoT transport indicators
Passenger kilometres travelled (pkt)	Regional level	MoT transport indicators
Travel times and distances	Regional level	New Zealand Household Travel Survey
Delay for road users (delay per vkt)	Regional level – urban areas	MoT transport indicators

Indicator	Geography	Source
Economic value indicators		
Gross domestic product (GDP) and labour productivity (GDP per worker)	National level	Statistics NZ – 2000–2014
	Regional level	Statistics NZ – 2000–2014
	Local level – area unit level	Estimates for 2007–2014 available from PwC's Regional Industry Database)[9]
Employment	Local level – area unit level	Statistics NZ – 2000–2014
	Local level – meshblock level	Statistics NZ – Census 2001, 2006, 2013
Population	Local level – meshblock level	Statistics NZ – Census 2001, 2006, 2013
Gross fixed capital formation	National level	Statistics NZ – 2000–2014
Personal incomes	Regional level	Statistics NZ – Linked Employee-Employer Dataset (LEED) for 1999–2015
	Local level – area unit level	Statistics NZ – Census 2001, 2006, 2013
Land values	Local level – property level or meshblock level	Council property sales audit files and/or ratings valuations (available through Corelogic or Auckland Council – MRCagney has access to recent Auckland data)
Import and export volumes and values	Regional/local level – available for individual ports	Statistics NZ – data series available 2000–2014
Retail sales	National level	Statistics NZ retail trade survey
	Local level – area unit level or lower	Electronic card spending data
Primary production	Regional/local level – depending upon commodity	Various data sources (see MWH 2012)

4.1.2 Commute output indicator

This indicator aims to establish a measure of the relative value or output of different road segments for their commuting function. We envisage using this indicator for the purposes of ranking the relative importance of road routes within large urban areas for commute purposes.

Commute trips make a significant contribution to economic activity by enabling connections between workers and firms. Particularly within large urban areas, a road's function in allowing firms to access the widest range of potential employees; and workers to access to the widest range of possible jobs, is critical to economic performance. Labour market accessibility is one of three microfoundations of agglomeration economies (Fujita et al 2001).

[9] PwC's Regional Industry Database allocates Statistics NZ's GDP and employment data by industry to area units across New Zealand, therefore also providing estimates of labour productivity to area units.

Development of the commute output indicator relies on two broad steps:

1. Constructing a model of the spatial distribution of commute flows for an urban region using car, public transport (bus and train) and walking modes. We base our model on census data that provides information on the origin (home) and destination (workplace) of census respondents.
2. Attributing a relative economic value to transport network segments by assessing the relative commute flow volumes using different network segments and weighting this volume by an average income measure for employment location, as a proxy for the value of the commute journey that is proportional to the value of the economic output produced.[10]

A detailed explanation of a potential methodology for this indicator is provided in appendix C. The indicator provides relative measures of the economic value of commute trips by weighting modelled commute trips by workplace income. We use median wage income at workplace locations to reflect the relative productivity of firms in a specific area and the economic value of enabling workers to access these jobs. For example, the result of this analysis is likely to place a higher value on trips serving city centre areas with higher average wages demonstrating the economic value of roads serving high-wage, high-productivity areas. A likely result is to place lower value on roads serving lower wage, lower productivity areas.

We find that the measure is feasible to calculate using available data, and appears to provide plausible results. The indicator extends current ONRC measures by providing more detailed information about the relative value of commute trips. Nevertheless, there are some limitations to this indicator:

- The indicator relies on modelled rather than actual commute flows to compare the value of different road segments. There are various reasons that our modelled flows may differ from actual flows.
  - While our modelled commute flows make use of data on actual home to work locations, we model routes between these locations using area unit centroids rather than individual addresses. This may mean that local-scale spatial allocation of trips to roads may not reflect real movement patterns, particularly for short distance trips. The model is likely to be most accurate at predicting longer-distance trips and use of arterial roads rather than shorter distance trips and use of local distributor roads.
  - Our modelled commute flows do not account for road congestion that may impact on route selection. In reality, car trips may be distributed more widely across the road network than suggested by our model, as the model attributes all trips to the fastest route (assuming no congestion). This is because people may choose to take longer, but less congested routes. Again, this may prioritise motorways and arterial roads over local distributor roads in our model results.
  - Our model allocates trips from the centroid of area units, therefore this approach may not reflect actual spatial distribution of trips, particularly for large area units with low population levels (such as rural areas).
- The indicator uses median income at trip workplace location to determine the relative economic value of different commute trips. This is only a proxy indicator for economic value and other indicators could alternatively be used. For example, average firm-level productivity or profit at the workplace destination could be alternative measures of the value of enabling commute access to different locations.

[10] We use wages as a proxy for the marginal productivity of the worker.

- Moreover, median incomes (or labour productivity) do not always reflect the value that individuals place on being able to access employment locations. For example, somebody travelling to a job in a low-income area may value that job more highly than another person travelling to a job in a high-income area, if they had fewer alternative options for employment.

Despite these limitations, a commute indicator is a useful output measure to include in the ONRC. A commute indicator, as outlined above, is likely to be economically meaningful due to the fact that commuting access enables labour market pooling and hence agglomeration economies. However, further work to refine the indicator and address its limitations (eg accounting for congestion) will be useful prior to including it in the ONRC.

4.1.3 Freight output indicator

This indicator aims to enable comparison of the value of roads for freight movement. Alongside the commute output indicator, a freight output indicator could be complementary in measuring roads' contribution to economic productivity by enabling movement of goods between businesses, to markets and to consumers. The following outlines a potential method for measuring relative freight outputs for different road segments across New Zealand. The method involves three key steps:

1. Establishing regional freight profiles reflecting different mixes of commodity movements within different regions, by using existing data collated for the National Freight Demand Study (NFDS) (MoT 2014).
2. Establishing average freight values for regions based on freight profiles, using data on the export value of internationally traded commodities.
3. Establishing a freight output indicator by applying the average freight values to each road segment's heavy vehicle volumes.

The indicator weights existing heavy vehicle volume measures by a value of freight measure established by measuring the average value of freight commodities at the regional level. A more detailed discussion of this methodology is included in appendix D. There are a number of limitations to this approach:

- **Use of regional rather than local- scale indicators of freight composition and value.** The approach relies on regional-scale averages of freight composition to determine freight values that are then applicable to all roads in a region. This approach has been used due to limited data about freight composition at smaller scales (eg for individual road segments or corridors). In reality, freight composition across different road segments within a region is likely to vary substantially. For example, freight movements of particular commodities may be particularly concentrated on specific corridors (eg imported car freight in Auckland may be concentrated on roads linked to the port). The impact may be to undervalue particularly important freight routes for valuable commodities, while overvaluing secondary freight routes within regions with high average values of freight.
- **Obtaining values of freight using trade values of commodities.** The method proposes to use overseas trade data to attribute an average value to each commodity group covered by the NFDS. There are four points to consider when using this data:
  - Value of a commodity exported or imported internationally may differ from the value of the same commodity that is only traded domestically. Using international export or import data may over-value some or all commodities. While this would not be problematic for the purposes of a relative indicator if all commodities are over-valued by a similar proportion, there may be problems if particular commodities have substantial differentiation between international and domestic trade prices.

- The value of commodities changes over time, so the measure of the value of freight movements along the routes will only be a point in time estimate. This could skew the relative value of the goods attributed to the routes as commodity prices rise and fall.
- Some commodities are not widely traded internationally or are moved intra-regionally. For example, aggregate is a major component of road freight tonnage, but is usually traded intra-regionally rather than internationally. In these cases, obtaining a reliable value from international trade data may not be appropriate, and other sources of local commodity prices may need to be investigated. If multiple price indices or sources are used, this may also present data consistency issues.
- Commodity groups are in some cases broad, and may include a wide range of goods of various values. For example, 'manufactured goods' or 'retail goods' include a wide range of goods and relying on average values will be a rough approximation for these types of goods. A concordance between ANZSIC[11] industries and the harmonised system was developed for the NFDS, which could be used to match trade flows and freight flows.

- **Using commodity value as a proxy for freight movement value.** The approach assumes that the value of a road for facilitating freight movement can be based on its current level of use and the current value of commodities transported on the road. This implies that the economic value of a particular road is always higher if the road is used for more valuable commodities. However, this may not reflect the level of productive economic activity that different roads facilitate. For example, a rural road may be lightly used for low-value commodities whereas an urban road may be heavily used for higher-value commodity move movement. The existence of the rural road may, however, facilitate a level of economic activity that is more substantial than that facilitated by the urban road where numerous alternative routes may be available and the productive activity or level of productivity is not so reliant on the existence of the particular road.
- **Using heavy vehicle indicators to reflect freight movement.** The approach relies on heavy vehicle counts as a proxy for the level of freight movement on a road segment. Two of the limitations to this measure are:
  - Heavy vehicle counts include vehicles other than freight trucks, including buses. In urban contexts, buses may constitute a significant proportion of heavy vehicle traffic which may distort the use of the figures for comparing levels of freight movement.
  - Heavy vehicle counts do not provide any information about whether the vehicle is carrying a full load or not. Empty running of trucks may be significant and should ideally be valued at a lower rate than fully loaded trucks.

Notwithstanding these conceptual and empirical issues, it would be useful to extend freight indicators to include some measure of the value of commodities being moved. If consistency at a national level is a goal, regional averages for freight values are likely to be most appropriate. Freight value provides an indirect measure of the quantity of economic activity potentially related to a road. Freight supply chains are strongly related to a second microfoundation of agglomeration economies – supply chain linkages between firms and consumers.

[11] Australia and New Zealand Standard Industrial Classification; a classification system for Australian and New Zealand industries for the collection and development of economic statistics.

4.1.4 Business-to-business interaction output indicator

Alongside measures of commute and freight outputs of roads, there may be additional value in measuring the value of road for facilitating B2B interaction. This measure would incorporate an alternative method for measuring freight movement as a subset of the wider B2B interaction indicator.

While the freight output measure discussed above considers heavy freight transport, it ignores other types of B2B transport including courier deliveries and passenger transport. These types of movements, and the infrastructure that facilitates these interactions, are particularly important for urban service economy industries. With the ongoing shift toward a more service-based economy where face-to-face interaction between businesses is important, measuring how infrastructure contributes to these types of interactions should ideally be considered in understanding the contribution of roads to economic productivity.

Road transport activity that is representative of B2B interaction can take the form of:

- heavy freight transport (ie truck vehicle movements transporting heavy goods inputs or outputs between businesses)
- light freight transport (ie courier vehicle movements transporting light goods inputs or outputs between businesses)
- passenger transport (ie passenger movements in cars, taxis, buses as well as walking and cycling that transports people between businesses for face-to-face meetings).

Our proposed approach to measuring B2B output across roads uses gravity modelling methods to estimate relative levels of business transport volume across the road network. A simplified approach would focus simply on volume measures, while a more complex approach could be supplemented by industry-sector data to weight volumes by relative economic value.

The following methods would use geographic information systems (GIS) and statistical methods, and the following data sources:

- employment demography (such as employee counts and industry sector)
- road network maps (including maximum road speed, and ideally, congestion data)
- business input-output tables for industry sectors
- business industry sector gross value added (GVA) or GDP.

We outline an indicative approach below:

1 Establish a spatial distribution of the production side of ‘economic mass’ at a regional or national scale by mapping the location of jobs (using employment demography data).

2 Undertake spatial cluster analysis to identify job concentrations (eg central business districts (CBDs) or concentrations of industry) (GIS analysis of employment data).

3 Model trip volume between centres using a gravity approach. Trip volume between job centres would be positively impacted by higher mass (ie higher numbers of jobs), and negatively impacted by generalised travel cost. Generalised travel cost could be most simply defined by Euclidian distance (ie ‘as the crow flies’), but could be more accurately defined as a function of transport network distance, congestion and potential transport speed enabled by the infrastructure.

4 Attribute trip volume to specific road segments, based on shortest or fastest network distance between centres.

5 Rank relative importance of road segments by level of modelled B2B travel volume.

Figure 4.1 Indicative B2B transport volume between major Auckland employment centres (based on job numbers, not adjusted for industry composition)

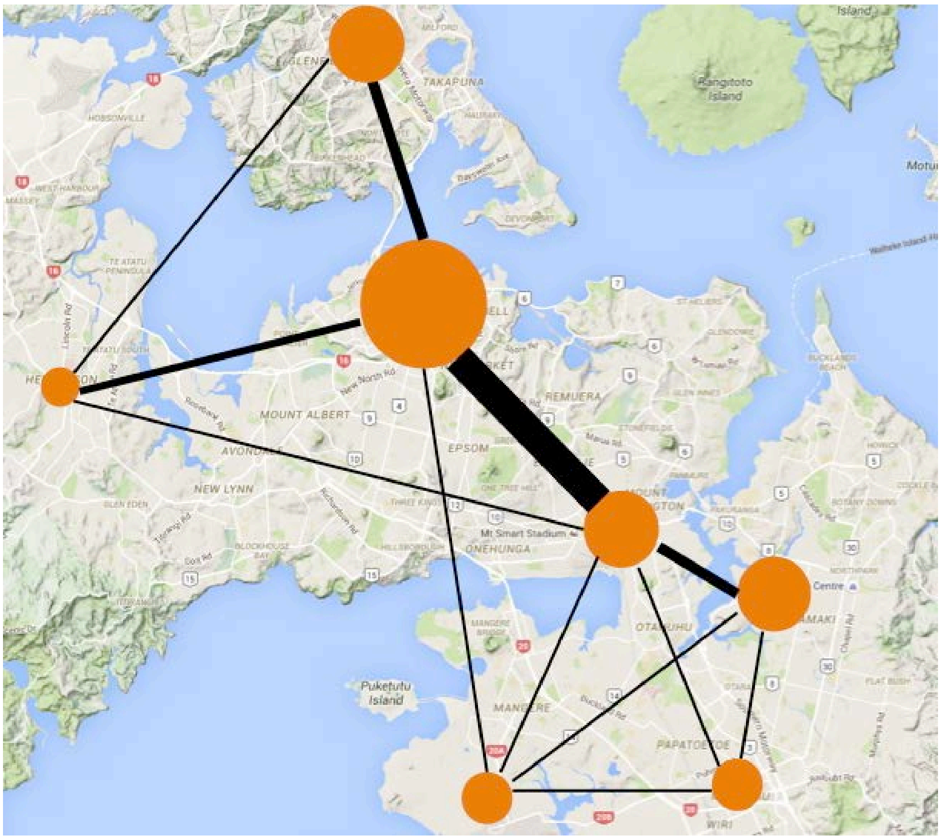


Figure 4.1 illustrates a rough estimate of relative volume of travel for B2B purposes, based on job numbers and Euclidian distance between centres. The next step would require attributing this travel volume to specific roads based on shortest or fastest route. Figure 4.1 also illustrates in broad terms how the geography of B2B travel within an urban region is likely to be distinct from the spatial pattern of commuting flows that link residential areas with employment centres.

This simplified approach could be extended in various ways. For example:

- Volume measures between centres could be adjusted for industry composition of different job centres. A differential 'transport task' could be applied to different industry sectors; for example, freight intensive sectors would contribute more to transport volume.
- Volume measures between centres could be adjusted according to inputs/outputs between industry sectors. For example, input-output tables could be used to estimate relative volume of travel between different sectors.
- Volume measures between centres could be adjusted for generalised travel cost between centres (rather than being based on Euclidian distance).
- Volume measures could be translated into value measures by weighting volumes by average GVA measures for different industry sectors.

The main strength of this indicator is in providing estimates of the spatial distribution of B2B trips across all types of travel volume (both heavy freight and light freight and passenger movement). Whereas, weaknesses of the approach include:

- The indicator may be more suited to urban areas with dense concentrations of jobs in centres and sub-centres. It is not clear whether it is possible to apply a similar methodology to more dispersed economic mass in rural areas. In some rural areas, trips between dairy farms and processing plants would be picked up if there is sufficient job density at the farm and at the processing plant.
- The focus of the analysis on movement between centres will cover a significant proportion of economic mass, but would ignore 'background' levels of dispersed employment and economic activity. Furthermore, this indicator will not be suited to some types of business trips, such as trips undertaken by tradespeople to residential locations.
- The indicator focuses on medium-long distance B2B travel between centres rather than micro-movement within centres that is important in service industry centres (eg walking between meetings). Nevertheless a similar approach could be used to model at a local-scale (eg within a CBD).The approach would provide purely modelled outputs of the transport task, and could not be verified with reference to empirical transport movement data.
- The indicator is relatively data intensive and would require some modelling resources.

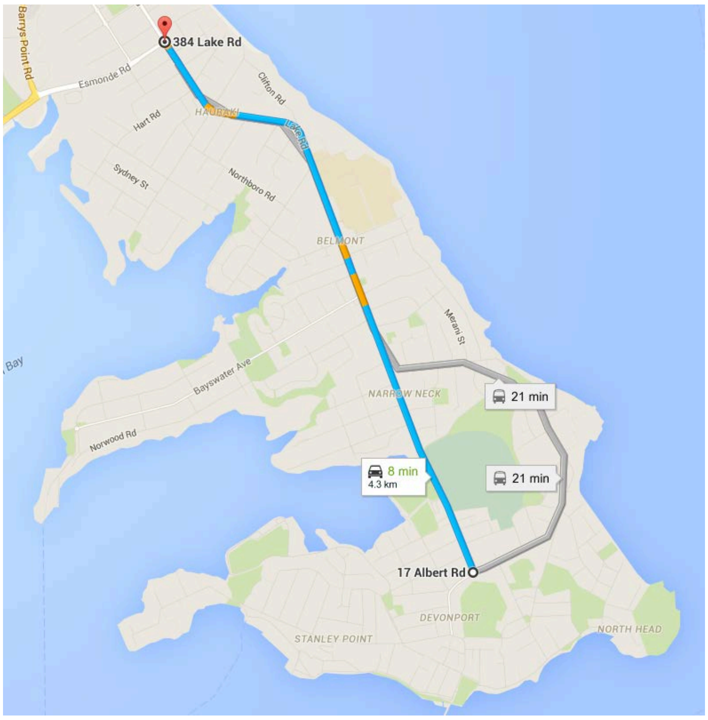
Despite these limitations, our proposed B2B travel indicator – or a fully developed variant thereof – is a potential useful inclusion in the ONRC. It is likely to be economically meaningful, as accessibility between firms underpins both supply chain linkages and knowledge spillovers, two microfoundations of agglomeration economies.

4.1.5 Second-best route/opportunity cost approach

In this section, we describe an approach to valuing roads based on the opportunity cost associated with deviating to a second-best route. This opportunity cost can be stated in terms of added transport costs (including time and vehicle operating costs) that people travelling on that road would incur if they were required to deviate onto an alternative road instead.

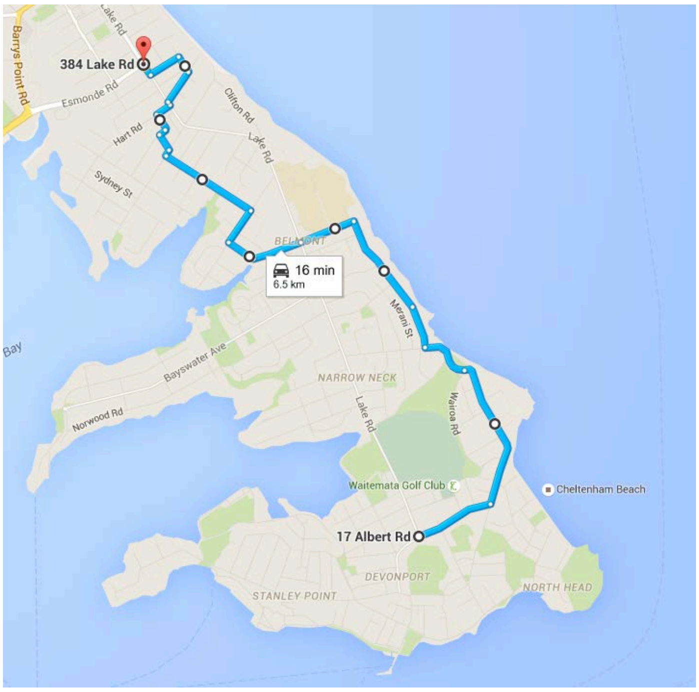
Promisingly, this enables the opportunity cost of individual road segment to be identified, which is equivalent to the absolute output that the road acts as an input to. In order to understand how this approach may work in practice, consider a case of a specific road link – Lake Road in Devonport/ Takapuna. Based on Google Maps data, it takes eight minutes (4.3km) to travel between Albert Rd (Devonport) and Esmonde Rd (Takapuna).

Figure 4.2 Lake Road (Auckland)



If Lake Road was not available, users would have to deviate substantially. Based on Google Maps data, estimated travel time would increase to 16 minutes (6.5km).

Figure 4.3 An alternative route to Lake Road



In table 4.2, we calculate the added annual transport cost that a single person driving on Lake Road would incur if they were required to deviate onto the alternative route. These costs include both monetary costs (ie added vehicle operating costs) and non-monetary costs (ie added travel time). However, they do not include external costs such as increased vehicle emissions or added congestion.

Overall, these calculations suggest that the value of Lake Road to a regular user, relative to the best alternative, may be relatively high – in the order of $2,000 per annum.

Table 4.2 Cost of using the 'second- best' option to Lake Road

	Lake Road	Second- best route	Difference
Travel time (TT) (min)	8	16	+8 min
Travel distance (km)	4.3	6.5	+2.2 km
Monetised TT (@$23.90/h)	$3.19	$6.37	+$3.19
Monetised vehicle operating costs (VOC) (@$0.31/km)	$1.33	$2.00	+$0.68
Annualisation factor (number of journeys per year on Lake Road)	500		
Total opportunity cost (added TT + VOC * days travelled)	$1,935		

This quick analysis suggests the approach is feasible to implement. For individual roads, online mapping tools (eg Google Maps) can be used to assess the cost of moving to a second-best road link instead. If it is necessary to assess a large number of road segments, it would be possible to apply Python scripting[12] and desktop-based GIS software to OpenStreetMap data (which provides data on free-flow traffic speeds and intersection delays, allowing for route assignment).

There are four key conceptual and practical challenges to implementing this approach. We set these out below, along with options for addressing them. Notwithstanding these challenges, we find that the second-best road measure provides an important indicator of the value that people place on the availability of individual road links. Unlike the other measures proposed above, which are relative indicators of output, this measure provides an absolute measure of the marginal value of individual roads. Consequently, it is likely to be useful for inclusion in the ONRC.

Challenge 1: The second best alternative approach does not address congestion in urban areas

The approach we have laid out relies upon free-flow traffic speeds and does not address congestion, which is likely to be a significant issue for many urban routes. In many cases, shifting traffic off one route onto another will increase delays for other people.

As a consequence, this approach would tend to undervalue urban roads relative to rural roads. Furthermore, it would tend to underestimate the value of parallel routes in highly congested areas.

In principle, there are several ways this could be addressed. One option would be to simulate the impact of removing specific road links using transport models. This is unlikely to be practicable due to the cost of running transport models.

A second option would be to attempt to undertake simple link-based modelling of congestion based on traffic volumes and road capacity. This could provide an indicative estimate of added delay for other drivers by using a US Bureau of Public Roads (BPR) function, which models congestion as a nonlinear function of traffic volumes as shown below:

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[12] Python is an open-source scripting language that can be integrated with GIS programmes such as ArcGIS.

Equation 4.1 is the BPR congestion function[13]

$$\tau(q) = t_{ff}\left(1 + \beta\left(\frac{q}{\kappa}\right)^{\rho}\right) \quad \text{(Equation 4.1)}$$

where $\boldsymbol{\tau}$ is measured in minutes per kilometre, t_{ff} is the free-flow time, q is demand and β, κ and ρ are constants.

This approach has several limitations. First, it would require additional data on traffic volumes on alternative routes and would entail an element of judgment by the analyst. Second, it would not capture delays at intersections, which can be significant but which are difficult to model without a microsimulation model.

A third option would be to benchmark roads based on their existing levels of congestion. For example, Google API or TomTom congestion data could be used to identify roads that are currently congested and penalise added travel times on second-best routes accordingly.

Challenge 2: There is difficulty in addressing cases where only one link is available

A second challenge, more likely to affect rural areas, is that there are cases when only one road link is available between two points. In order to analyse these cases, it would be necessary to make assumptions about what the second-best road would be. However, it is worthwhile noting that all the economic activity within that region is enabled by the route.

A simple way to do this would be to assume that the second-best road would be a dirt or gravel road following a similar alignment. This would result in added travel time as well as increased depreciation/ wear and tear on vehicles. However, this approach may not be accurate in situations where infrastructure such as tunnels or bridges is required to address topological constraints (eg SH94/Milford Road). In those situations, a basic gravel road may follow a significantly different route[14].

Challenge 3: Results for individual road segments may not be consistent with results for entire routes

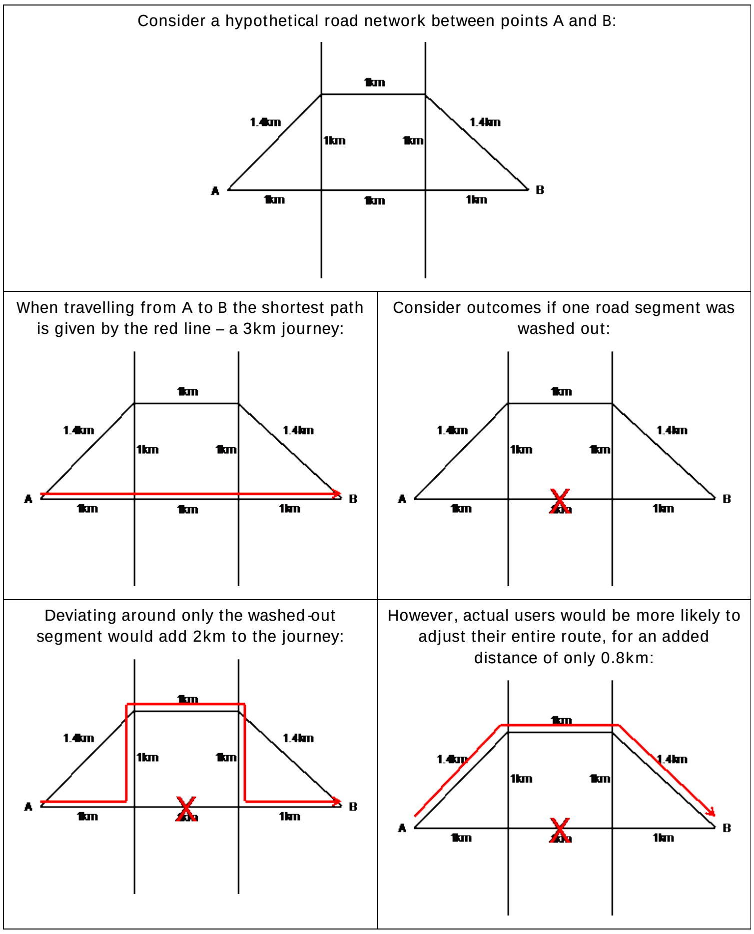
The third technical challenge concerns the consistency of results. This challenge arises because the optimal detour between two intersections (ie the second-best detour for a single road segment) may not be the same as the optimal detour for the entire route.

Figure 4.4 illustrates a hypothetical case in which this may occur. In this case, the structure of the road network allows users travelling between points A and B to choose between several alternative routes. An analysis of detours around an individual road segment may not capture the fact that users may rethink their entire route.

[13] Source: Wallis and Lupton (2013).

[14] In fact, the second-best route to Milford Sound may not be a road at all – in the absence of a road, users may be required to visit the Sound by helicopter or cruise ship, which would result in either significant financial cost or considerably longer travel times. These cases do not invalidate this approach but they do suggest that it may be appropriate to apply a bespoke analysis for individual roads facing similar issues.

Figure 4.4 Inconsistency between a segment- based and route- based assessment



This example suggests two things. First, analysing second-best routes on a segment-by-segment basis is likely to overstate actual costs to users. Second, it is relatively simple to address this issue on a case-by-case basis by applying some practical judgment. In the Lake Road example above, it was simple to manually specify an alternative route. However, doing so for a large number of roads is likely to be impractical.

Challenge 4: Additional data and analysis is needed for different types of road users

Lastly, we note that it would be necessary to address challenges with the availability of data on people and freight movements on roads in order to fully implement this approach. While existing data provides a basis for assessing the cost of moving to a second-best route for people in vehicles, it does not comprehensively measure pedestrian and cycle movements, or track vehicle occupancy (eg bus occupancy). This undercount will have an impact on some types of roads more than others (eg roads in urban areas will have more pedestrian and cycle activity than some state highways).

Some of these issues can be addressed by collecting and reporting better data on road users. For example, public transport ticketing data can be used to measure the number of PT users that would incur additional costs from moving to a second-best road. In our analysis of seven case study roads in Auckland in chapter 5, we have used available PT user data and cycle monitoring data to include these categories of road users.

However, there are also additional conceptual difficulties in measuring the cost of moving to a second-best road for pedestrians and cyclists. People's choices about where to walk or cycle are likely to be influenced by the (perceived) safety of different roads and the convenience and amenity of pedestrian and cycle facilities. In some cases, this may mean choosing a route that is less direct but safer or more convenient. A measurement principally based on added travel time may tend to under-state the value of those roads for walking or cycling.

Existing data does not necessarily enable these factors to be modelled. While good data on road crashes is available, measured crashes are not a perfect proxy for perceived safety of roads. For example, people may simply choose not to walk on roads that feel excessively unsafe – with the result that no car-pedestrian crashes are recorded on those roads. Similarly, data on pedestrian and cycle facilities may not be detailed enough to enable a quantitative assessment. Consequently, it is likely that further research or data collection is needed.

4.2 Opportunities for improving input measures

Alongside improved measures of road outputs, further development of input measures can be particularly important for comparing the relative efficiency or performance of different roads in producing outputs. Improved input measures may be most relevant for the performance monitoring framework within the ONRC rather than for initial classification purposes.

This section explores data sources and methods for estimating the costs associated with individual roads. It sketches out approaches to valuing the cost of inputs to roads and identifies key parameters to be used in analysis. It also identifies some conceptual and practical challenges to robustly measuring road inputs.

In doing so, we note that it may not be appropriate to include measures of the fixed costs associated with roads, as these are often (although not always) sunk costs[15]. We note this point and consequently suggest that it is most appropriate to think of any calculation of the fixed costs of providing transport corridors as a form of 'shadow price' that reflects the fact that resources were previously invested in corridors. Shadow prices can be thought of as ways of reflecting hard-to-monetise factors in an organisation's internal decision-making[16]. They do not have any direct financial implications for organisations as a whole.

This shadow price reflects the fact that past decision makers would have expected to obtain higher outputs from costlier transport corridors. Furthermore, while many roads are constructed on a pay-as-you-go basis, there is nonetheless an opportunity cost associated with transport investments. For example, higher levels of transport investment may crowd out public or private investment in other assets that may have paid a return over time.

Estimating the shadow price of providing transport corridors is a way of recognising these choices and trade-offs. In our view, it can be a useful input to asset management, as it helps to enable cases where more resources were invested in the expectation of a higher return. However, these fixed costs could equally well be excluded to obtain an alternative estimate of input costs.

With that in mind, table 4.3 summarises relevant sources of data that could be used to make an estimate of the overall cost of inputs to roads. We have chosen to exclude costs borne substantially by users from our analysis of costs. We focus on:

- fixed costs of providing road corridors
- external costs borne mainly by non-road-users.

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[15] In some cases, it has been possible to reuse transport land for other purposes. For example, since its establishment as a state-owned enterprise in the 1980s, Kiwirail has sold off a significant amount of excess land on rail corridors.

[16] For example, business units within large corporations may provide services to each other, such as business analytics or human resources. To avoid the 'overconsumption' of internally provided services, business units may be required to 'charge' each other for time spent on projects. This does not have any effect on the organisation's overall bottom line.

Table 4.3 Sources of data on cost of inputs to transport networks

Type of cost	Source	Method of inferring costs	Spatial coverage	Years available
Fixed costs of providing corridors				
Opportunity cost of land	LINZ or council GIS layers provide data on size and type of roads.	Council rating valuations data provides information about the cost of land in specific locations.	Road data: All New Zealand. Ratings data: availability must be confirmed on case-by-case basis.	Recent years only, although historical data on land values could be sourced from, eg QV.
Construction and renewal costs (capex)	LINZ/council data on size and type of roads, plus total current value of road networks owned by the Transport Agency or other RCAs. An alternative, more detailed source would be the Transport Agency's road asset management database (RAMM).	Annual capex costs can be inferred by applying a rate of return to current asset valuations (from the Transport Agency or regional transport agencies).	Road data: All New Zealand. Asset valuations: availability must be confirmed for individual regions and individual roads.	Recent years only, although historical asset valuations could be sourced from old annual reports.
Maintenance and operations (opex)	LINZ/council data on size and type of roads, plus Transport Agency data on expenditure on local roads and state highways by region. An alternative approach would be to use forward cost planning rates for different categories of roads.	Transport Agency regional expenditure data can be apportioned out to individual roads on a proportional basis. We have tested this approach based on accumulated regional road maintenance, operation and renewals expenditures over 10-year period, scaled for cost inflation.	Road data: all New Zealand. Transport Agency regional expenditure data available for all regions.	Transport Agency regional expenditure data available for 2005–2014.
Public transport operating subsidies	GTFS data on total public transport-service-kilometres.	Transport Agency expenditure data. Average annual cost inferred by apportioning out accumulated regional PT operating expenditures over 10-year period, or using planned forward expenditures.	GTFS data: availability confirmed for Auckland, Wellington and Christchurch; other regions unknown. Transport Agency regional expenditure data available for all regions.	Recent years only – reliable GTFS feeds have only recently been compiled for urban areas. Transport Agency regional expenditure data available for 2005–2014.
External costs borne substantially by non-users				
Road crash costs	The Transport Agency's Crash Analysis System (CAS).	The Transport Agency's EEM provides estimates of the social cost of different types of crashes in	CAS data available for all New Zealand.	CAS data available for 2000–2015 (year to date).

Type of cost	Source	Method of inferring costs	Spatial coverage	Years available
		appendix A6.		
Rail crash costs	Kiwirail/MoT Rail Safety Statistics	EEM provides estimates of the social cost of different types of crashes in appendix A6	Rail Safety Statistics available for all New Zealand; a specific data request is required for data at a detailed geographic level	2003–2014
Particulate matter emissions	Health and Air Pollution in New Zealand (HAPINZ) model	HAPINZ estimates the cost of mortality and morbidity associated with transport emissions at an area unit level. Area unit-level estimates can be apportioned out to roads based on the relative size of roads in each area.	All New Zealand	Based on 2006 Census data; parameters for recent population growth, changes to emissions levels, and increases in the value of statistical life can be input into model.
Greenhouse gas emissions	No data source confirmed. It may be possible to estimate using data on vehicle volumes or particulate matter (PM) emissions.	EEM factors can be used to estimate the social cost of these externalities.	N/A	N/A
Noise externalities				

4.3 Opportunities for improving productivity measures

Productivity measures for roads consider the relationship between output and input costs. This provides indicators of the relative efficiency of roads in providing various outputs. Section 4.1 identified multiple potential output measures, as a single comprehensive measure of output is difficult to calculate using existing data sources. In contrast, section 4.2 established a common measure for total inputs to roads.

The various output and input measures can be combined in different combinations to produce multiple indicators of productivity. We also note that existing traffic or PT volume indicators can be combined with input cost measures to reasonably easily establish some initial productivity indicators.

For example, we suggest the following productivity indicators, once fully developed, for different road segments may provide useful guidance for investment planning and asset management purposes within the ONRC:

- Freight productivity:
  - freight output measure/total road input costs

    or
  - (using existing data) HCV volumes/total road input costs
- PT productivity
  - PT users/total road input costs
- Total passenger productivity:
  - (vehicle users + PT users + cyclists + pedestrian volumes)/total road input costs
- Commute productivity:
  - commute output indicator/total road input costs
- Productivity relative to second-best route:
  - cost of moving to second-best route/total road input costs.

Productivity measures are not necessarily relevant for classifying roads into different ONRC categories. As discussed above, it is most appropriate to categorise roads using output measures, as these reflect the role that roads serve, independent of their costs. However, productivity measures can be used to monitor the relative performance of roads **within** ONRC categories.

5 Testing application of improved measures to case studies

This chapter reports on testing the proposed approaches to measuring inputs, outputs and productivity of roads using Auckland case studies. It provides a starting point for further analysis in the next stage of the research and provides an opportunity to test ideas and the mechanics of the calculations on a small scale using a few selected routes.

The aim of testing the methods is to provide a 'proof of concept' and confirm the feasibility of rolling out the approach across a broader nation-wide selection of roads or identify where further work is needed before implementation of the indicators. On these road segments we tested the following approaches:

- commute output and productivity
- freight (unweighted) output and productivity
- second-best alternative measure.

Of the approaches outlined in chapter 4, we did not test the freight output measure using the regional-scale freight profile approach. Nor did we test the proposed business-to-business interaction measure. The untested freight indicator is more suitable for comparing roads across regions, rather than our case study selection of road segments that are all within a single region. Testing of the business-to-business interaction indicator would require further data collation and analysis that could be undertaken as part of future research (refer section 8.3).

5.1 Selecting case study road segments

To test the proposed methods, a sample of road segments was selected based on identified criteria. The unit of analysis for our methods is a road segment (ie a short length of road), rather than a complete road length (eg Dominion Road in its entirety).

Our identified criteria for case study selection did not aim to provide a representative sample of roads in Auckland. Rather, the selection allowed us to understand in which areas (and situations) the method would be easy to apply and where it would be challenging to apply. We note that this selection of roads is limited, and a wider selection of case study segments could allow for testing the application of the new indicators across a broader range of road types and segment lengths (eg inter-regional state highways).

The criteria used for the selection of case study roads is summarised in table 5.1.

Table 5.1 Criteria for case study road segment selection

Criterion	Discussion
Data availability	Roads and routes which had monitoring sites (and AADT counts) for more than a single point were preferred.
Range of road types	A range of road types (eg urban arterial, rural, motorways) was preferred. This has implications for output side and cost side for the proposed relative productivity indicator.
Range of surrounding land uses and values	A variety of land uses in the corridors surrounding the road (retail, industrial, residential, rural) would enable us to develop our approach for the opportunity cost of the road.
Variety of current AADT counts	Our proposed approach is to improve the current measures of economic productivity, based on AADT. A variety of AADT would serve to provide a useful benchmark.

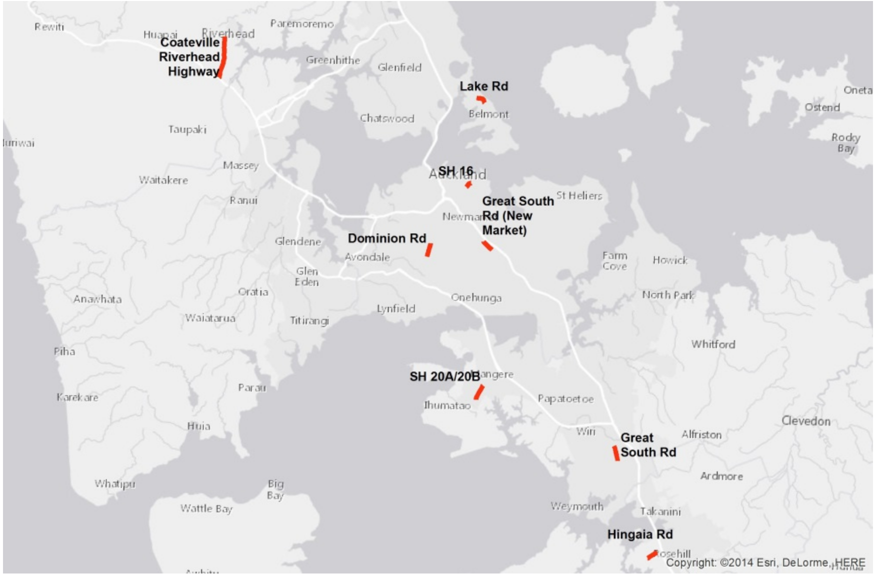
Criterion	Discussion
Broad geographic spread	The use of routes over a wide area serves to test the proposed approach and identify any geographic bias in the method. Note: this is likely to be intrinsically linked to the land use in the areas surrounding the road.
Additional areas of economic importance	The routes towards the Ports of Auckland were favoured as these are likely to carry HCV with goods, a point of difference to roads dominated by passenger traffic. We also favoured roads linking Auckland International Airport, as another route of national economic importance

The roads selected did not have to meet every criterion. The research team determined that for testing purposes, selecting a wide range of roads and routes (and therefore understanding the applicability of the methods in a wide variety of situations or where further work is required) was a key principle.

We considered that the following eight road segments provided a good sample to test the proposed methods. The location of the road segments is illustrated in figure 5.1 below.

- Dominion Road
- Coatesville Riverhead Highway
- Great South Road (Newmarket)
- Great South Road (Manukau)
- Lake Road
- Hingaia Road
- SH20A (airport)
- SH16 (Grafton Gully).

Figure 5.1 Location of case study road segments in Auckland



The eight road segments represent a range of road types with varied surrounding land uses, varied AADT counts, different traffic mixes and different levels of use across a range of users including bus users and cyclists. SH16 has the highest AADT count. The Coatesville Riverhead Highway has the highest percentage of HCV travelling along the road but the fewest vehicles travelling along the road. Dominion Road is representative of an urban arterial with a mix of public transport, cycling and traffic users. Great South Road has the highest use by bus passengers. There is also a mix of urban and rural roads, as well as two different data sources (which contributes to our understanding of the ability to generalise the method).

Table 5.2 summarises traffic, public transport and cycling and pedestrian movement on each road segment.

Table 5.2 Passenger and freight movement on case study road segments in Auckland

Road name	**Dominion Road**	**Coatesville Riverhead Highway**	**Great South Road (Newmarket)**	**Great South Road (Manukau)**	**Lake Road**	**Hingaia Road**	**SH20A**	**SH16**
Type	Urban arterial	Rural	Urban arterial	Urban arterial	Urban arterial	Rural/suburban	Motorway/freight route	Motorway/freight route
Road segment	Between Lambeth Rd and Balmoral Rd	Between Riverhead Rd and SH16	Between Greenlane Rd and Karetu Rd	Between Orams Rd and Corin Ave	Bayview Rd to Eversleigh Rd	Hinau Rd to Kuhanui Rd	Kirkbride Rd to Montgomerie Rd	The Strand to Alten Rd
Traffic count (AADT)								
Date	Week starting 11 June 2015	Week starting 22 February 2014	Week starting 6 March 2015	Week starting 5 June 2015	Week starting 23 July 2015	Week starting 12 February 2015	2014 annual[17]	2014 annual
Traffic monitoring point	Between Balmoral Rd and Wiremu Rd	Between Riverhead Rd and SH16	Between Omahu Rd and Aratonga Rd	Between Orams Rd and Grand Vue Rd	Onepoto Rd to Bayview Rd, north of Takapuna Grammar	Between Bridgeview Rd and Oakland Rd	SH20A west of Kirkbride Rd	Stanley St east of Alten Rd
Light vehicles	23,235	5,632	18,615	16,202	27,629	10,816	41,874	41,090
Heavy vehicles	1,050	435	776	688	1,098	763	2,297	3,525
Total	24,285	6,067	19,391	16,890	28,727	11,579	44,171	44,615
Public transport users (HOP)								
Date	Tuesday 17 March 2015		Tuesday 17 March 2015	Tuesday 17 March 2015	Tuesday 17 March 2015	Tuesday 17 March 2015	Tuesday 17 March 2015	Tuesday 17 March 2015
Caveats							HOP data significantly undercounts Airbus users	HOP data may be imperfectly matched to Outer Link

[17] Estimate of the average daily traffic for a specified calendar year. Most traffic counts have been undertaken at the particular count site over four weeks or more in the year and are seasonally adjusted.

Road name	Dominion Road	Coatesville Riverhead Highway	Great South Road (Newmarket)	Great South Road (Manukau)	Lake Road	Hingaia Road	SH20A	SH16
HOP patronage	7,342		10,660	1,769	670	27	765	107
Number of buses	471		548	176	78	2	210	73
Cycle and pedestrian counts								
Date/time	Tuesday 3 March 2015		Tuesday 3 March 2015	Wednesday 4 March 2015	Thursday 5 March 2015	Wednesday 4 March 2015	Wednesday 4 March 2015	Tuesday 3 March 2015
Cycle monitoring point			Great South Rd/ Campbell Rd/ main highway intersection			Cyclists counted at Hingaia Pensinsula School		
Cyclists/day	420		294	96	402	16	12	126
Pedestrians/day	No data available							

5.2 Testing the commute output indicator

The method outlined in section 4.1.1 and discussed in detail in appendix C was tested to compare commute outputs across the case study road segments. The results are summarised in table 5.3

Comparison of the case study road segments shows a wide range of commute outputs across the eight road segments. This variation is expected, as the case studies were selected for their diversity and to understand in which situations the potential methods require refinement or further investigation. We find that SH16 at Grafton supports travel for the highest total income of commuters, at over $800 million, compared with the lowest value for the Coatesville Riverhead Highway at $30 million. This suggests SH16 provides 27 times more commute output than the Coatesville Riverhead Highway. The higher values reflect high numbers of passenger commute movements, combined with high numbers of passengers using the road to access high income-producing employment locations. In the case of SH16 at Grafton, many users will be commuting to high-paying jobs in the Auckland CBD.

The findings highlight the role of the commuting flow model in determining modelled commute numbers on different road segments. It is likely that actual commute numbers on roads will differ from the modelled results. This is due to the model's approximate attribution of trips to routes based on shortest geometric paths between area unit centroids, and lack of accounting for congestion effects on route choice. Acknowledging these types of limitations to the model will be important for interpreting results if this approach is applied more widely. The commuting flow numbers in table 5.3 represent one-way commute trips, so if comparing with AADT levels, these numbers could be doubled to represent both home-work and work-home trips. It should be noted that if comparing commute flows with AADT, commute flows will only ever be a proportion of total AADT, since AADT includes various other trip purposes (non-commute trips such as education and leisure trips, freight trips).

Testing the indicator on case study segments shows there are likely to be cases where the model underestimates actual commute flows. For example, Great South Road at Manukau is modelled as having only 735 daily commuters driving (or total two-way flows of 1470) (table 5.3), despite AADT of 16,000 light vehicles (see table 5.2 previously). In this case, low numbers may reflect the presence of nearby parallel Southern Motorway that is likely to receive the bulk of modelled commute trips. On other tested road segments, modelled commute levels appear to constitute a sensible proportion of actual AADT, given the context and likely function of the road. For example, on Dominion Road modelled commute flows are 4,068*2/ 23,235 (34% of light vehicle AADT), while on SH20A serving the airport, commute flows are a much lower proportion of total trips given considerable airport transfer trips likely on the route (1,986*2/41,874, or 9% of light vehicle AADT).

The tested road corridors have a reasonably wide range of average incomes for the passengers using the road for commute purposes. For instance, the average commuter modelled to be using Great South Road at Manukau is travelling to an employment location with an average income of $36,000. At SH16 Grafton, the average commuter is travelling to a location with an average income of $57,000. This is consistent with intuitive understandings of commuters using SH16 accessing higher-paid CBD jobs while those using Great South Road in Manukau more likely to be commuting to lower-paid jobs in South Auckland.

Variations in modelled average incomes for commuters using different road segments suggest an income-weighted commute measure will in some cases produce different results than a measure of traffic volume. However, we also note that the range of variation in modelled average incomes is likely to be less than a single order of magnitude. In this example, the highest average incomes were approximately 50% above the lowest. Variations in traffic volumes between roads are much larger.

Table 5.3 Commute flows for case study road segments (modelled using census data)

Road name	Dominion Road	Coatesville Riverhead Highway	Great South Road (Newmarket)	Great South Road (Manukau)	Lake Road	Hingaia Road	SH20A	SH16
Estimated daily commuters (one- way flows)								
Drivers and passengers	4,068	624	6,177	735	4,221	2,322	1,986	13,827
Public transport users	1,641	0	1,683	171	474	3	111	27
Walking and cycling	186	15	342	267	261	42	0	375
Total	**5,895**	**639**	**8,202**	**1,173**	**4,956**	**2,367**	**2,097**	**14,229**
Total income of commuters	$286,453,400	$30,036,000	$388,461,500	$42,639,000	$233,429,000	$108,414,800	$99,295,500	$811,649,000
Average income on road segment	$48,593	$47,005	$47,362	$36,350	$47,100	$45,803	$47,351	$57,042

5.3 Testing the value of the road segment relative to second-best option

The method outlined in section 4.1.5 was tested on eight case study roads. This approach calculates the value of travel time saved given the existence of the road, compared with the second-best alternative route.

Like the commute output indicator, the different roads had a wide range of scores using this measure, reflecting the diversity of the case studies selected. The measure placed the highest value on road segments in areas with less dense road networks. In these locations, the second-best alternative route was substantially longer, so the value of the roads existence was higher. In dense urban locations with high road network density, there are more alternative routes and therefore a shorter detour would be taken, compared with areas where there are fewer alternative routes.

The highest value road using this indicator is Hingaia Road, with the costs of moving to the second-best alternative route being $53 million. This high cost reflects a relatively low number of users, but a long additional travel time for the second – best alternative (16.2 minutes). In contrast, Coatesville Riverhead Highway had the lowest value from this indicator at around $3 million due to a low number of users and low alternative travel time for the second-best route (an additional 1.9 minutes). The method also highlights that for roads with high numbers of users but low levels of additional travel time on the second best route, the value of the road can still be high (for example, SH16 Grafton Gully). It should be noted again that a limitation of this approach is in not modelling congestion on alternative routes, so it likely understates the value on routes that have high traffic levels.

Table 5.4 Value of road relative to second- best option – outputs for case study road segments

Road name	Dominion Road	Coatesville Riverhead Highway	Great South Road (Newmarket)	Great South Road (Manukau)	Lake Road	Hingaia Road	SH20A	SH16
Estimated annual users								
Car occupants (1.3 occupants/ vehicle; 365 annualisation factor)	11,025,051	2,672,248	8,833,021	7,688,052	13,109,825	5,132,192	19,869,264	19,497,402
Public transport users (75% HOP uptake; 300 annualisation factor)	2,936,800	0	4,264,000	707,600	268,000	10,800	306,000	42,800
Cyclists (300 annualisation factor)	126,000	0	88,200	28,800	120,600	4,800	3,600	37,800
HCVs, excluding buses (365 annualisation factor)	241,843	158,775	118,736	198,320	377,370	277,791	775,366	1,264,574
Advantage over second- best route								
Added uncongested travel time on second-best route (min)	1.7	1.4	0.8	1.0	0.6	13.8	3.1	1.5
Added travel distance on second-best route (km)	1.1	1.9	1.2	0.8	0.5	16.2	2.4	1.2
Cost of moving to second- best route								
Car occupants	$9,906,767	$2,547,267	$4,918,614	$4,137,884	$4,420,638	$45,161,595	$33,358,223	$16,369,713
PT users	$2,095,475	$0	$1,425,218	$296,700	$70,636	$65,756	$485,304	$47,593
Cyclists	$207,310	$0	$166,769	$34,988	$97,690	$120,080	$13,035	$72,214
HCVs excluding buses	$514,750	$489,745	$233,936	$286,838	$355,747	$7,639,140	$3,400,398	$2,867,593
Total cost	$12,724,301	$3,037,012	$6,744,537	$4,756,411	$4,944,711	$52,986,571	$37,256,960	$19,357,113

5.4 Testing the calculation of road input costs

Testing our method for calculating road input costs showed a high level of variation in input cost per kilometre for the various road segments. The input costs considered included corridor costs (infrastructure and PT operations, but not private operations costs) and external costs (crash and air quality costs). Here, we have only calculated a single measure of input costs for the entire corridor, although we note that the data we have collected would allow us to attribute a share of corridor costs to PT operations[18]. Table 5.5 summarises the results of our analysis. Appendix E provides more detailed methodological discussion on testing the calculation of input costs in an Auckland context.

SH16 at Grafton has the highest input costs of almost $6 million per kilometre. This high cost is explained by being a land-intensive motorway in an inner-city location with high levels of vehicle use. In contrast the Coatesville Riverhead Highway had input costs of just $150,000 per kilometre, being a rural road with lower vehicle use. The vast majority of input costs are attributable to land costs, with high input costs for urban arterial roads reflecting central urban locations with high land values. PT operating and crash costs also made a significant contribution to input costs, while road maintenance and renewal costs were generally minor in comparison.

[18] Typically, buses or on-street light rail only require one lane in each direction. In some cases, this is a dedicated PT lane, while in others it is shared with other vehicles. Data on the number of vehicle lanes could be used to allocate a share of corridor costs to PT purposes. This allocation would be most valid on roads with dedicated PT lanes. Identifying those roads would require matching LINZ data on road widths with other data on the location of dedicated PT lanes.

Table 5.5 Calculating road input costs for case study road segments

Road name	Dominion Road	Coatesville Riverhead Highway	Great South Road (Newmarket)	Great South Road (Manukau)	Lake Road	Hingaia Road	SH20A	SH16
Corridor costs								
Length of road (km)	0.97	2.84	0.82	1.04	0.75	0.76	1.09	0.45
Number of lanes	4	2	4	4	4	4	4	5
Road area (m^2)	13,802	57,718	11,847	13,478	8,799	7,845	14,449	9,209
Annual PT service-kilometres	457,789	0	447,742	182,469	58,165	1,518	229,869	62,689
Estimated land value ($2,011)	$28,693,550	$796,942	$38,597,046	$9,109,654	$22,041,861	$3,133,201	$10,172,595	$40,335,057
Estimated book value of road	$1,022,798	$2,989,678	$859,791	$1,090,993	$784,723	$798,951	$1,705,572	$697,706
Annual return on land (at 6%) [A]	$1,721,613	$47,816	$2,315,823	$546,579	$1,322,512	$187,992	$610,356	$2,420,103
Annual return on capital (at 6%) [B]	$61,368	$179,381	$51,587	$65,460	$47,083	$47,937	$102,334	$41,862
Estimated annual maintenance, operating and renewal costs [C]	$28,661	$83,776	$24,093	$30,572	$21,989	$22,388	$200,493	$82,016
Estimated annual PT operating costs [D]	$909,846	$-	$889,878	$362,653	$115,602	$3,017	$456,860	$124,593
Estimated total annual corridor cost [A+B+C+D]	$2,721,488	$310,974	$3,281,381	$1,005,264	$1,507,186	$261,334	$1,370,043	$2,668,575

Road name	Dominion Road	Coatesville Riverhead Highway	Great South Road (Newmarket)	Great South Road (Manukau)	Lake Road	Hingaia Road	SH20A	SH16
External costs								
Annual average crashes (2009–2014):								
Fatal injury	0	0.2	0	0.2	0	0	0	0.2
Serious injury	0	0	0.2	0.4	0.2	0	0	0.2
Minor injury	8.2	1.6	3.2	2.6	3	0.2	2	1.8
Non-injury	19.2	2	15.2	13.4	3.8	0.6	4	8
Estimated annual crash costs [E]	$1,118,678	$1,017,246	$728,822	$1,622,342	$502,274	$29,686	$196,416	$1,401,671
Estimated cost of poor air quality (PM10) [F]	$66,872	$120,098	$138,488	$246,030	$148,966	$5,324	$32,619	$6,284
Total corridor and external costs [A+B+C+D+E+F]	$3,907,038	$1,448,317	$4,148,691	$2,873,636	$2,158,426	$296,344	$1,599,078	$4,076,529
Corridor and external costs per km	$4,027,874	$509,971	$5,059,379	$2,763,112	$2,877,901	$389,926	$1,467,044	$9,058,953

5.5 Testing calculation of road productivity

Finally, measures of road outputs and inputs were combined to produce various productivity indicators for road segments shown in table 5.6. These measures indicate the level of a particular output (freight, commute travel or PT/cyclist travel) for each unit of input. It should be noted that all productivity measures (aside from the second-best route measures) do not reflect meaningful values in and of themselves. Rather, they provide a relative score that allows for comparison or ranking between roads, within each productivity measure. The scores across the different productivity measures should not be compared. For example, the value of the commute productivity indicator for Dominion Road should not be compared with its freight productivity indicator.

The five productivity indicators tested show a wide range across the tested road segments. For example, commute productivity is highest for Hingaia Road with a value of 366, compared with a score of 15 for Great South Road Manukau. The high productivity at Hingaia Road reflects high numbers of car commuters travelling on a suburban fringe road with low input (predominantly underlying land) costs. In our assessment, Hingaia Road supports the highest contribution to labour’s share of value added, per unit of input, out of all the road segments tested.[19]

Freight productivity is highest for Hingaia Road. It is also relatively high for SH20A and SH16, but much lower for Great South Road, Newmarket and Dominion Road. Freight productivity is mainly influenced by the levels of HCV movements on the segments. In contrast, the urban arterial corridors have the highest level of PT productivity, illustrating the different functions of different roads.

With regard to the total passenger productivity indicator, Hingaia Road scores highest at 17, while SH20A also scores highly at 13. Coatesville Riverhead Highway has the lowest total passenger productivity.

Productivity measures for moving to the second best route show a very high level of variation. Hingaia Road again scores highest at 179. This reflects the relatively sparse road network in the rural-suburban fringe area that makes the second best alternative route far longer. In contrast, generally roads in inner-urban areas where road networks are denser have much lower scores by this indicator. The Coatesville Riverhead Highway is an exception, further investigation may help to understand this result. This also highlights the limitation of using a small number of case studies (refer to section 5.6).

As previously mentioned, the case studies have been purposefully selected to represent a range of road types, with varied surrounding land uses, and are geographically spread across Auckland. The observed results, across the range of indicators, reflect the diversity of the roads selected. Note that it is likely that the roads selected in the case studies sit within different ONRC categories (as they currently stand).

[19] The remuneration of workers represents the total labour contribution to New Zealand’s value-added. The higher the labour contribution, the greater New Zealand’s value-added (or GDP).

Table 5.6 Productivity indicators for case study road segments

Road name	Dominion Road	Coatesville Riverhead Highway	Great South Road (Newmarket)	Great South Road (Manukau)	Lake Road	Hingaia Road	SH20A	SH16
Freight productivity (HCVs/input costs)	0.06	0.11	0.03	0.07	0.17	0.94	0.48	0.31
Public transport productivity (PT users/ input costs)	0.75	–	1.03	0.25	0.12	0.04	0.19	0.01
Total passenger productivity (car users + PT users + cyclists/input costs)	3.61	1.85	3.18	2.93	6.25	17.37	12.62	4.80
Commute productivity (income-weighted commuters/input costs	73.32	20.74	93.63	14.84	108.15	365.84	62.10	199.10
Productivity relative to second-best route (cost of moving to second-best route/input cost)	3.26	2.10	1.63	1.66	2.29	178.80	23.30	4.75

5.6 Limitations of the case study approach undertaken

We have used a small number of case studies to test the feasibility of the indicators developed as part of this study. The successful application to case studies as shown in sections 5.2 to 5.5, indicates the methods can be applied, at least at a basic level.

Notwithstanding, we have tested only a small number of roads which are limited to the Auckland region. It may be difficult to generalise the approach and implement the use of the indicators without further feasibility testing in other regions. For example, not all RCAs will have the data required (eg PT patronage counts) to successfully implement the indicators developed in this study. Identification of these issues will enable further refinement and development of the current suite of indicators.

Therefore further testing of new case studies, in particular of road segments in different parts of New Zealand, will be helpful to understand whether any adjustments to the indicators and the method are required. It will also help to develop an understanding of how successful a nation-wide rollout of the indicators could be, including an idea of the extent to which judgement is required to interpret the results.

6 Implementation guidance

In this section we provide some guidance on how our recommended improvements and indicators (summarised in chapter 9), once fully developed, could be integrated with the existing ONRC functional classification categories, in the short and long term. We note that the new indicators developed by this research remain at an experimental stage, and further research will be valuable for further testing and refinement of these indicators ahead of widespread implementation. This section provides a road-map toward potential integration with the ONRC functional classification criteria, which can be formalised when the indicators are complete.

6.1 Use of a PT productivity or total passenger productivity indicator within the ONRC context

The productivity indicator developed to incorporate a wider range of passenger movements is a relative productivity indicator. It requires a benchmark for comparison. As PT is provided on a local basis, ie implementation of a PT productivity or total passenger productivity will be done by a RCA within a region, a PT productivity or total passenger productivity indicator requires regional benchmarks to be established.

We suggest that roads can be classified for ONRC purposes, as being 'high relative productivity' or 'low relative productivity' within ONRC functional criteria classification categories. These two further subcategories for the ONRC can assist with prioritising roads for maintenance purposes or broader transport planning purposes with a clearer link to the economic productivity of the road. For example, highlighting low productivity roads allows for interrogation of how productivity on the road may be increased; either by reducing input costs or increasing outputs.

6.1.1 Creation of the productivity indicator benchmark database

To establish a set of regional benchmarks, we recommend that the total passenger productivity indicator is estimated for a set of roads from each ONRC category for each region in New Zealand (refer table 6.1).

The benchmark database should contain more than one road from which an average can be taken, to make the individual functional classification categories – region benchmark indicators. There will be 96 benchmarked indicators in total (six ONRC functional classification categories times 16 regions).

$$PT\ or\ Total\ passenger\ productivity\ benchmark = \bar{x}_{i,j}$$

i = ONRC functional classification category

j = Administrative region

Table 6.1 Sample PT or total passenger productivity indicator benchmarks

	National	Regional	Arterial	Primary collector	Secondary collector	Access
Northland						
Auckland						
Waikato						
Bay of Plenty						
Gisborne						
Hawke's Bay						
Taranaki						

	National	Regional	Arterial	Primary collector	Secondary collector	Access
Manawatu-Whanganui						
Wellington						
Tasman/Nelson						
Marlborough						
West Coast						
Canterbury						
Otago						
Southland						

6.1.2 Example calculation

Lake Road, Auckland has an estimated total passenger productivity of 6.3. If the benchmarked total passenger productivity for regional roads in Auckland is 10.0[20], Lake Road, Auckland is classified as 'low relative productivity'. This could be used by Auckland Transport for road maintenance or transport planning purposes.

Example ONRC decision trees are included in appendix F.

6.2 Use of a commute productivity indicator within the ONRC context

The productivity indicator developed for commuting purposes requires a threshold value - which can be used as a point of comparison. We suggest that a collection of roads are identified, the commute productivity indicator is estimated for each of the roads, and the information is collated into a reference database of benchmarks. From this, roads can be assessed against the benchmark level of productivity.

Within each individual ONRC functional category, roads can be classified as being 'high relative productivity' or 'low relative productivity' on several indicators. These two further subcategories for the ONRC can assist with prioritising roads for maintenance purposes or broader transport planning purposes as we establish a clearer link to the economic productivity of the road.

Over time, more roads can be assessed and included in the database, which will help make the comparison of productivity more robust. Note that this is a dynamic approach which means that roads are able to move from being categorised as high relative productivity to low relative productivity and vice versa over time (refer to section 7.6 for the frequency of update).

6.2.1 Creation of the benchmarks database

The commute productivity indicator needs a regional perspective for the benchmark database. In the development of the commute productivity indicator, we have used a measure of income from the census. Incomes vary across regions, even after adjusting for industry composition within areas, so the commute indicator needs to have regional benchmarks to account for this variation. We suggest the inclusion of a

[20] Note this is an illustrative example only.

New Zealand average may be relevant for the Transport Agency in prioritising nationally allocated funds, which should only be used for roads which overlap administrative boundaries. These would mainly be state highways.

To establish a set of regional benchmarks, we recommend the commute indicator is estimated for a set of roads from each ONRC category for each region in New Zealand (refer table 6.2).

The benchmark database should contain more than one road from which an average can be taken, to make the individual functional classification categories – region benchmark indicators. There will be 102 benchmarked indicators in total (six ONRC functional classification categories times 16 regions plus one New Zealand average).

$$Commute\ productivity\ benchmark = \bar{x}_{i,j}$$

i = ONRC functional classification category

j = Administrative region

Table 6.2 Sample commute productivity indicator benchmark database

	National	Regional	Arterial	Primary collector	Secondary collector	Access
Northland						
Auckland						
Waikato						
Bay of Plenty						
Gisborne						
Hawke's Bay						
Taranaki						
Manawatu-Whanganui						
Wellington						
Tasman/Nelson						
Marlborough						
West Coast						
Canterbury						
Otago						
Southland						
New Zealand average						

Note the suggested use of an average, rather than median, to establish the productivity indicator benchmarks. The use of the mean as a measure of central tendency will be skewed by extreme values but the median will result in equal share of roads classified as high relative productivity and low relative productivity. This may be less useful for policy purposes such as prioritisation and identification of the very high relative productivity roads.

Alternatively, a higher threshold could be used, such as the 75th percentile. This would enable identification of the top 25% of roads and strengthen the relationship between the roads and economic productivity. A higher threshold would reduce the influence of very low relative productivity roads.

6.2.2 Example calculation

The database will store the benchmark to indicate the threshold which roads will be assessed against. As an example, Lake Road in Auckland has been classified as belonging to the regional ONRC category. We have estimated its commute productivity as 108. If the benchmark regional road in Auckland has estimated commute productivity of 100[21], then Lake Road, Auckland is classified as 'high relative productivity'. Lake Road's categorisation as 'high relative productivity' regional road could be used by Auckland Transport, in its asset management planning, to prioritise Lake Road for maintenance (eg quality, frequency) over standard roads or broader transport planning purposes.

Example ONRC decision trees are included in appendix G.

6.3 Use of a freight productivity indicator within the ONRC context

The freight productivity indicator is independent of regional variation in terms of the value of goods being moved. Notwithstanding, the composition of goods being moved varies between regions but the value of the goods being moved could be derived from international markets, thus the value is not derived regionally. We recommend a national benchmark database is developed for the freight productivity indicator.

As with the commute productivity indicator, roads can be classified for ONRC purposes, as being high relative productivity or low relative productivity within ONRC functional criteria classification categories. These two further subcategories for the ONRC can assist with prioritising roads for maintenance purposes or broader transport planning purposes with a clearer link to the economic productivity of the road.

6.3.1 Creation of the productivity indicator benchmark database

The benchmark database should contain an average freight productivity database for each of the six ONRC functional classification categories. A large sample of roads within each ONRC functional classification category should be used to calculate the average to ensure the benchmarked average productivity is as robust as practical and possible.

$$Freight\ productivity\ benchmark = \bar{x}_i$$

i = ONRC functional classification category

Table 6.3 Sample commute productivity indicator benchmarks

	National	Regional	Arterial	Primary collector	Secondary collector	Access
New Zealand average						

6.3.2 Example calculation

SH20A has an estimated freight productivity of 0.5. Assuming SH20A has been classified as a national road in the functional classification, and the benchmark for national roads across New Zealand is 0.4[22], SH20A is classified as high relative productivity.

[21] Note this is an illustrative example only.

[22] Note this is an illustrative example only.

Meanwhile Great South Road (at Newmarket) has a freight productivity indicator of 0.03, so would be classified as low relative productivity.

6.4 Use of a second-best route indicator

The second-best route productivity indicator developed in section 4.1.5 will be a phase shift in the ONRC away from outputs to the productivity of roads. We anticipate this would require some time to implement.

The second-best route productivity indicator is an absolute measure of the productivity of roads. As such, it does not require a benchmark to compare roads against. The productivity of roads can be directly allocated to ONRC functional classification categories and can concord to other ONRC outcomes such as customer levels of service. Each ONRC functional classification category would have an associated minimum productivity threshold for classification, eg to be classified as a national road, the minimum second-best route productivity indicator would need to exceed 50[23] – refer to table 6.4.

Table 6.4 Sample second best route productivity indicator

	National	Regional	Arterial	Primary collector	Secondary collector	Access
Second-best route productivity indicator – minimum threshold	Declining scale/threshold →					

6.4.1 Example calculation

We estimated the productivity relative to the second best road for the case studies, as outlined in table 5.6. As observed, Hingaia Road, Karaka, Auckland has the highest absolute measure of productivity estimated at 179, while Great South Road (at Newmarket) has the lowest measure of productivity estimated at 1.63.

The indicator has suggested prima facie counter-intuitive results, and we would interrogate the economic activity in the land surrounding Hingaia Road and Great South Road further before classifying the roads. However, the results have an alternative interpretation, of network resilience. The much higher productivity of Hingaia Road is a feature of the road network in the area. If Hingaia Road did not exist, then the additional travel time would be great because of few and distant alternatives. On the other hand, there are many alternatives to Great South Road, which explains the low productivity estimate.

6.4.2 Challenges to implementation of a second-best route indicator

Network resilience is not necessarily correlated with economic output, thus an indicator measuring the network resilience does not capture a road's overall contribution to economic output. Combining the second-best route productivity indicator with some other measure of labour input (eg total passenger movements) would strengthen the relationship to economic output. We recommend this as an area for future research.

[23] Note this is an illustrative example only.

There is also the requirement to consider congestion effects and route optimisation in the analysis. In our simplified approach for feasibility testing, we did not consider the impact of congestion on the productivity indicator. If a road was unable to be used, the vehicles normally using the road would need to be diverted to an alternative, which would impact on the travel time and productivity indicator.

Similarly, the behaviour of travellers could differ if an entire road or just a road segment was unable to be used, which also impacts on the travel times and the estimation of the second best route productivity indicator (refer section 4.1.5). We have not considered this variability in our assessment. We recommend that this variation and the impact of congestion are areas of future research.

6.5 Implementation of recommendations over time

The benchmark databases will take some time to develop, so a piecemeal approach could be undertaken. The ONRC guidelines have four examples of roads which have been classified:

- Auckland – Devonport
- Western Bay of Plenty – Paengaroa area
- Waitaki – rural area north of Oamaru
- South Island state highways – southern area.

The roads within these areas should be assessed in terms of the commute productivity, freight productivity and second-best route indicators as part of the next tranche of case studies and testing. The case studies can form the initial benchmark databases and roads can continue to be added over time.

Following the ONRC functional classification categories, we recommend that the database is constructed in a similar order of priority:

- national
- regional
- arterial
- primary collector
- secondary collector
- access.

6.6 Frequency of update

The ONRC and benchmarks should be periodically updated, to ensure that trends in the outputs of roads and inputs of roads are accounted for. We do not consider it is necessary to update the ONRC and benchmarks frequently, because traffic volumes and changes to the patterns of people movements occur slowly over time. Traffic volumes and PT patronage change relatively slowly in most areas – between 0% and 2% per annum. Highest growth rates are in the range of 5% per annum on parts of Auckland's motorway network, and perhaps 10% on parts of Auckland's public transport network. This implies that updating data on transport volumes on a five-yearly cycle (or even a 10-yearly cycle) will generally be sufficient to capture major movements.

Triggers for reclassification could include when new investment, which could significantly alter traffic volumes or changes to patterns of people movements, takes place. Such investment could include:

- new road construction that results in down-grading of some existing roads
- road improvements/corridor changes, especially when they result in changes to the function of the corridor (eg bus lanes added).

Significant land-use changes could also trigger an update. For example, district or private plan changes (eg changes to land use from residential to non-residential, changes in the intensity of land use) could translate to increased traffic flows over time. It should be noted there will be a lag between a plan change, a further lag between the plan change being approved and an observable change in economic activity on the land and associated traffic flows.

6.7 Challenges for implementation

6.7.1 Data availability

One of the key challenges to implementing the proposed relative productivity indicators will be the availability of data. Within urban areas the availability of data on active mode use and PT is limited, which will be even more scarce in rural areas and smaller RCAs. Although we note that in some areas the overall change in total passenger movements estimated will be small, for example in areas which are not served by PT and active use is not high.

There will need to be an emphasis towards collecting this information by RCAs over time, to fully implement the relative productivity indicators recommended in this paper.

Data on the movements of freight is also limited. We believe there is enough data for an inter-regional freight productivity indicator but an intra-regional freight productivity indicator is difficult to determine using publically available data.[24] There may be an opportunity for central government, local authorities or RCAs to be given the mandate to collect this information, which would support building the freight productivity indicator.

6.7.2 Competing outcomes

There is a high likelihood of generating competing outcomes, for example a road could be classified as high relative productivity for the commute productivity indicator but low relative productivity for the freight productivity indicator. This is expected to be a common scenario, as roads serve multiple purposes. In these scenarios, we recommend that the roads' 'high relative productivity' status is maintained.

6.7.3 Interpreting outcomes

We have recommended including relative productivity measures as subcategories within the ONRC functional classification categories. Note that our recommendation is to compare the relative productivity of a road to the relevant benchmark for the ONRC category for use within the ONRC context. Highlighting 'low productivity' roads allows for interrogation of how productivity on the road may be increased; either by reducing input costs or increasing outputs.

However, there will be instances of overlapping categories. For example, a high relative productivity regional road could have a higher commute productivity indicator than a low relative productivity national

[24] We find that electronic data collected for road user charges is limited at this point in time. See note 30 for further details.

road. This does not mean that the national road contributes poorly towards economic outcomes. The nature of the relative productivity indicator requires a benchmark – which we have adapted to the current ONRC categories. Over time, the movement towards productivity measures, rather than functional classification criteria, will avoid overlapping categories.

We understand that there are instances where state highways have been given a lower classification than some regional roads, so in practice, the ONRC has instances of flexibility and application of professional judgement. Over the long term, movement towards an absolute productivity measure could remove some of the classification issues by using a single productivity metric instead of many criteria in the current functional classification system.

6.7.4 Changes over time

As roads are included in the benchmark database, the estimate of the average productivity will change and the classification of some roads, categorised as high relative productivity could switch categories to low relative productivity and vice versa. However, as more roads are included, the estimate of the average productivity will vary less and fewer roads will need to be recategorised.

7 Conclusion

We find that the current ONRC functional classification criteria do not adequately capture total passenger movements. In particular, the current measures on public transport and active modes along roads are underdeveloped in the ONRC context. We identified several improvements to ONRC measures which would support the understanding of the economic value of movements of people and goods along roads. Our focus was on improvements that could be feasibly implemented with existing data available and did not require undue analytical effort. During the course of the research we noted a tension between developing measures that provide the most complete and accurate information about a road's contribution to economic productivity and the need to establish measures that can be practically implemented in the context of data and resource limitations.

Roads have a function to move people and goods between locations. We found that weighting existing traffic volume indicators can contribute to estimating the value of movements along a road. For example, commute trips represent the movement of labour as an input to production. The road enables workers to get to a place of production, where economic activity takes place and economic output is produced. Weighting commute trips by income, a measure of a worker's contribution to value-added, provides an estimate of the value of production supported by the road.

Similarly, weighting heavy vehicle volume indicators by the average regional freight value of transported commodities will provide an estimate of the value of the movement of goods on roads.

Productivity indicators require a base to determine the magnitude of output relative to the size of the input. Incorporating the input costs of roads is essential to determining the productivity of roads, to understand the resources consumed in supporting movements of people and goods and generating economic output. This means the output can be assessed on a per-unit of input basis and roads can be compared on a like-for-like basis, to each other or to a benchmark. As such, the productivity indicators are a relative measure in that they should be compared to something else to understand their value.

An absolute measure of productivity is preferable – which can be achieved using a second-best route approach. This is an absolute productivity indicator, which measures the travel time difference between the preferred route and the second best route – it is a measure of the opportunity cost of the road. This has clear direct linkages to performance measurement targets.

8 Recommendations

On the basis of our research, we make six main recommendations:

1. Further development of the indicators and additional case studies (the next steps for this research).
2. Collate data where gaps have been identified as part of the next tranche of case studies (short-term implementation).
3. Include improved data on PT usage to develop a better understanding of total passenger movements on road corridors (short-term implementation).
4. Weight existing transport volume measures by various indicators to obtain more accurate reflections of economic value (short-term implementation).
5. Include input costs for roads (short-term implementation).
6. Move towards measures of overall productivity rather than counts of vehicles and outputs (long-term implementation).

In making these recommendations, we have considered the cost of collecting and processing data and reporting new output measures. The case studies we have undertaken in this report suggest the data required for our short-term recommendations is generally available to the Transport Agency, regional transport agencies or to RCAs. Furthermore, as we discussed in chapter 6, it would be possible to implement these measures within the scope of the existing ONRC.

We discuss recommendations 3 to 6 below in terms of implementation over the short term and long term.

8.1 Short-term recommendations

8.1.1 Inclusion of additional PT data

We consider the ONRC functional classification criteria do not capture overall people movements very well, particularly in large urban centres. Specifically, the criteria for PT usage, the number of buses per hour or movements of people per hour, does not necessarily relate very closely to the number of PT passengers.

This is likely to have two effects on the understanding and estimates of road usage.

First, the importance of PT corridors is likely to be understated in large urban areas (eg Auckland, Wellington, Christchurch). PT accounts for a significant share of overall passenger movements on key routes within these centres. The people-movement function of roads will be underestimated on PT corridors.

Second, the movement of freight is likely to be over-stated on PT corridors. Buses are counted as HCVs on many routes, leading to an over-estimate of the freight movement function of roads on PT corridors.

In addition, measurement of active modes is underdeveloped in the ONRC, which also contributes to an underestimate of the total people movements. We consider that the underestimate will be most significant on roads leading to town centres and high streets (eg Queen St, Auckland). However, in most other areas the proportion of trips made using active modes will be small and the undercount will not be significant.

Therefore we recommend that closer attention is given to integrating data on PT patronage along roads into ONRC functional classification criteria. Recent developments in electronic ticketing provide new data sources on PT patronage that should be used. This can be done independently and without reference to the indicators we have developed in this study.

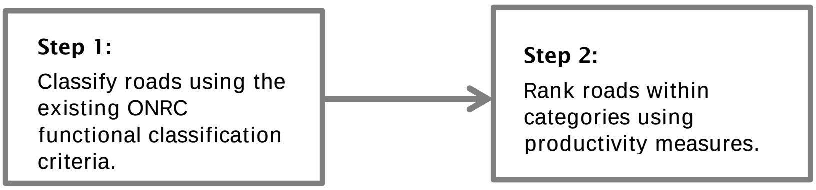
8.1.2 Inclusion of additional data on types of journeys

The use of the road to generate economic output – travelling to work and between businesses, or in the case of freight movements, moving goods between locations, is also poorly understood within the ONRC context. The implicit assumption that higher AADT and HCV counts are related to greater economic output does not take into account factors such as variation in industry composition and labour productivity.

For example, consider two roads which have similar AADT and HCV counts, but one road supports travel to work in high labour productivity industries and the other supports travel to work in low labour productivity industries. Currently the ONRC would classify these roads similarly, but the economic output supported by these roads will be different.

Weighting the movements by (i) income, as we have suggested in the commute productivity indicator, and (ii) value of freight commodities, as we have suggested in the freight productivity indicator, improves the understanding of roads' relative contribution to economic output.

The ONRC can be used in its current form to first classify roads, and then within categories the relative productivity measure discussed can be used to rank roads. Therefore we recommend including data on types of journeys, incomes and freight value within the ONRC functional classification criteria as illustrated below.



8.1.3 Inclusion of input costs for roads

In section 4.3, we explored the idea of estimating the productivity of roads, which requires estimates of the outputs of roads and inputs of roads. The recommendation to include PT data and data on types of journeys will help to develop a picture of the output of a road, with a clearer link to the economic activity that the road supports.

We include this as a short-term recommendation as we consider much of this information is already available. Including the inputs of roads, and the data recommended above, enables the estimation of the relative productivity indicators developed in chapters 4 and 5. Although further research to refine the indicators is required, we have outlined in chapter 7 some initial guidance on using a productivity measure to provide an idea of how the indicators can be applied in practice.

8.2 Long-term recommendations

Over the long term, we recommend moving away from a quantity measure of outputs to a productivity measure of roads, particularly for performance management purposes. A productivity measure is likely to be more closely aligned to the ONRC performance measure and targets.

We recommend that the productivity indicator includes:

- a numerator and a denominator – to attempt to measure both output values and input costs

- a measure of the absolute, not relative, value of roads.

The second best route indicator, our final measure explored (refer section 4.1.5), is a measure which incorporates the output and input of roads and attempts to measure an absolute value of roads. This appears to be a promising avenue to pursue over the long term, but requires further investigation to resolve methodological issues such as congestion measurement and total passenger movements. It is grounded in fundamental economic principles. Most importantly, it addresses the economic concept of the opportunity cost of the road – the value of the second best alternative. A marginal analysis of the travel time impact for the movements of people and goods if a road segment were no longer available, provides a sound estimation of the opportunity cost of the road.

Second, by comparing second-best route outputs with road input costs allows for measurement of the productivity of a road. By including the input costs, this productivity indicator explicitly considers the scarcity of resources and their use.

Third, by incorporating the external costs we produce a holistic view of the input costs of a road, relative to the outputs it supports. Note that this feeds into generating an estimate of the productivity of a road and that our recommended treatment of external costs is different to others. In the EEM, externalities are treated as outputs of roads and negative externalities are treated as negative benefits. We have recommended that costs (such as crash costs or environmental impacts) are incorporated as inputs which contribute to generating economic output (as the road's output).

8.3 Areas for future research

Our research has not focused on the place value of roads nor its welfare effects. Further research into the place value of streets should be undertaken and the role of place value indicators within the ONRC clarified. Consideration could be given to:

- identifying retail high streets and town centres using zoning data
- using parking prices or land prices as a proxy for place value[25]
- gathering more detailed data on pedestrian movements and pedestrian density.

After considering the measures which could indicate a road having a significant place value, an additional category in the ONRC functional classification criteria for streets, which mainly have value as a place, could be included. A challenging area for investment strategy is likely to be streets which have both high place and movement values.

Further research into the welfare effects of roads should also be investigated. The welfare effects are poorly or incompletely captured by existing data but could be incorporated into our framework as data quality improves. For example, we note that data on commuting and freight flows may underestimate the true value of roads used primarily for leisure or recreational trips. Recognising these outputs is important even if existing data is not sufficient to measure them.

The application of these indicators to railways could be explored. For example, commute and freight output indicators may be useful for improving understanding of the various contributions of urban rail networks to economic performance.

[25] Note that this is only applicable if minimum parking requirements have been removed

Finally, ongoing consideration should be given to how changing data availability and increased technological sophistication in spatial data analysis may present new opportunities for improved indicators of the contribution of transport infrastructure to economic activity at the micro-scale. The concepts presented in this research may highlight opportunities to guide collection of new types of data that will make an expanded set of indicators more viable.

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Appendix A: Data availability

Table A.1 outlines the availability of indicator variables in terms of geographic relevance, time period coverage, regional coverage and the nature of its availability (ie is the data free and publicly available; publicly available at a price; status uncertain?).

Table A.1 Indicator variables currently available

Indicator	Geography	Time- period available	Coverage[26]	Availability of data	Source
Road use measures					
AADT – light vehicle counts	Local level – individual roads	1975–2015	Various sites throughout New Zealand	Free/publicly available	NZ Transport Agency
AADT – heavy vehicle counts	Local level – individual roads	1975–2015	Various sites throughout New Zealand	Free/publicly available	NZ Transport Agency
Rail freight movements	Regional/ local level – inter-regional freight flows	2011–2014	By port	Free/publicly available	MoT freight information gathering system
Public transport boardings	Local level – individual services	2012–2015	Auckland	Available from Auckland Transport	AT HOP data (Auckland only)
	Regional level	Annual, 2009–2014	Regional	Free/publicly available	MoT transport indicators
Cycle counts	Local level – selected cycle routes	2010–2015	Auckland and by regional	Available	AT cycle count data (Auckland only); counters in other regions
Pedestrian counts	Local level – selected streets	Annual, 2013–2014	Various sites throughout New Zealand	Free/publicly available	Heart of the city pedestrian counts (Auckland city centre only); counters in other locations
Commuting flows (by mode of travel)	Local level – flows between individual area units	2013	Regional	Held by MRCagney	Statistics NZ – 2013 Census data
Vehicle kilometres travelled (vkt)	Regional level	Annual 2000–2014	Regional	Free/publicly available	MoT transport Indicators
Passenger kilometres travelled (pkt)	Regional level	Annual, 2006–2014	Regional	Free publicly available	MoT transport Indicators
Travel times and distances	Regional level	Annual, 2003–2014	Regional	Free/publicly available	Household Travel Survey

[26] Regional indicates the data is available for all 16 regions in New Zealand unless otherwise stated.

Indicator	Geography	Time- period available	Coverage[26]	Availability of data	Source
Delay for road users (delay per vkt)	Regional level – urban areas	Annual 2003–2014	Regional	Free/publicly available	MoT transport indicators
Economic value indicators					
Gross domestic product (GDP) and labour productivity (GDP per worker)	National level	Annual, 2000–2014	For New Zealand	Free/publicly available	Statistics NZ – 2000–2014
	Regional level	Annual, 2000–2014	Regional	Free/publicly available	Statistics NZ – 200–-2014
	Local level – area unit level	Annual, 2007–2014	By area unit	Held by PwC	Estimates for 2007–2014 available from PwC's Regional Industry Database[27]
Employment	Local level – area unit level	2000–2014	By area unit	Price/publicly available	Statistics NZ – 2000–2014
	Local level – meshblock level	2001, 2006, 2013	By meshblock	Price/publicly available	Statistics NZ – Census 2001, 2006, 2013
Population	Local level – meshblock level	2001, 2006, 2013	By meshblock	Price/publicly available	Statistics NZ – Census 2001, 2006, 2013
Gross fixed capital formation	National level	1993–2015	Not available by region	Free/publicly available	RBNZ – 1993–2015
Personal incomes	Regional level	1999–2015	Regional	Free/publicly available	Statistics NZ – Linked Employee-Employer Dataset (LEED) for 1999–2015
	Local level – area unit level	2001, 2006, 2013	By area unit	Price/publicly available	Statistics NZ – Census 2001, 2006, 2013
Land values	Local level – property level or meshblock level	Sales coverage in the Auckland region from 2011 onwards, ratings valuations in line with council revaluations (2011 and 2014)	Regional	Held by MRCagney	Council property sales audit files and/or ratings valuations (available through Corelogic or Auckland Council – MRC has access to recent Auckland data)
Import and export volumes and values	Regional /local level – available for individual ports	Monthly, 1988–2015	By port	Free/publicly available	Statistics NZ – data series available 2000–2014

[27] PwC's Regional Industry Database allocates Statistics NZ's GDP and employment data by industry to area units across New Zealand, therefore also providing estimates of labour productivity to area units.

Indicator	Geography	Time- period available	Coverage[26]	Availability of data	Source
Retail sales	National level	Quarterly, 2006–2014	For New Zealand	Free/publicly available	Statistics NZ retail trade survey
	Local level – area unit level or lower	Monthly, 2008–2015	Disaggregation by region is not publicly available.	Free/publicly available	Electronic card spending data
Primary production	Regional/local level – depending upon commodity				Various data sources (see MWH 2012)

Appendix B: AADT – analysis of comprehensiveness

Table B.1 highlights the coverage of AADT counts across New Zealand and Auckland. We find that there is good coverage of state highways (by the Transport Agency) and roads in Auckland (by AT) for vehicle movements. In addition, the evolution and development of electronic ticketing cards has produced a rich dataset of bus use in Auckland through the data collected from AT Hop.

However, counts of other road use, for example pedestrian counts and cycling, are underdeveloped at this stage. In particular, data on pedestrian counts are limited to the city centre.

Table B.1 Availability of different measures of vehicle and passenger flow in Auckland

Data type	Source	Number of monitoring points	Years covered	Notes/caveats
Vehicle movements on state highways	NZTA annual traffic counts	563 Auckland monitoring points (1,919 nationwide)	1975–2014	A mix of nationally managed sites (6% of total), regionally managed sites (76%) and virtual sites (18%)
	NZTA monthly traffic counts	16 Auckland monitoring points (116 nationwide)	2008–2015	Based on automatic monitors. Breaks out light and heavy vehicle movements
Vehicle movements on local roads	AT traffic counts	3,390 monitoring points in Auckland	2012–2015	Based on periodic traffic surveys at selected local roads. Most roads have only been sampled on a single occasion. Some counts also available prior to 2012
Public transport passenger movements	AT HOP	All PT routes with HOP card boardings	March 2014 onwards	Access to data guarded by AT. Over 70% of public transport journeys now use AT HOP
Cycle counts	AT automatic cycle monitoring	9	2013–2015	
	Annual cycle counts	85	2007–2015	Conducted first week of March
Pedestrian counts	Heart of the city automatic pedestrian counters	17 city centre sites	2013–2015	No data available outside of city centre

Table B.2 Availability of NZ Transport Agency state highway traffic monitoring data for regions

Region	National telemetry sites	Region managed counting sites	Virtual sites	Total
Northland	4	68	1	73
Auckland	14	361	188	563
Waikato	15	164	26	205
Bay of Plenty	14	72	44	130
Gisborne	3	18	0	21
Hawke's Bay	4	46	13	63
Taranaki	4	48	6	58
Manawatu–Wanganui	9	100	3	112
Wellington	10	111	38	159
Nelson/Marlborough	7	35	5	47
Canterbury	11	194	16	221
West Coast	4	50	2	56
Otago	14	121	2	137
Southland	5	62	7	74
Total	118	1450	351	1919

Source: www.nzta.govt.nz/assets/resources/state-highway-traffic-volumes/docs/SHTV-2010-2014.pdf

Appendix C: Detailed commute output indicator methodology

The commute output indicator aims to establish a measure of the relative value or output of different road segments for their commuting function.

Development of the indicator relies on two broad steps:

1 Constructing a model of the spatial distribution of commute flows for a region using car, public transport (bus and train) and walking modes.

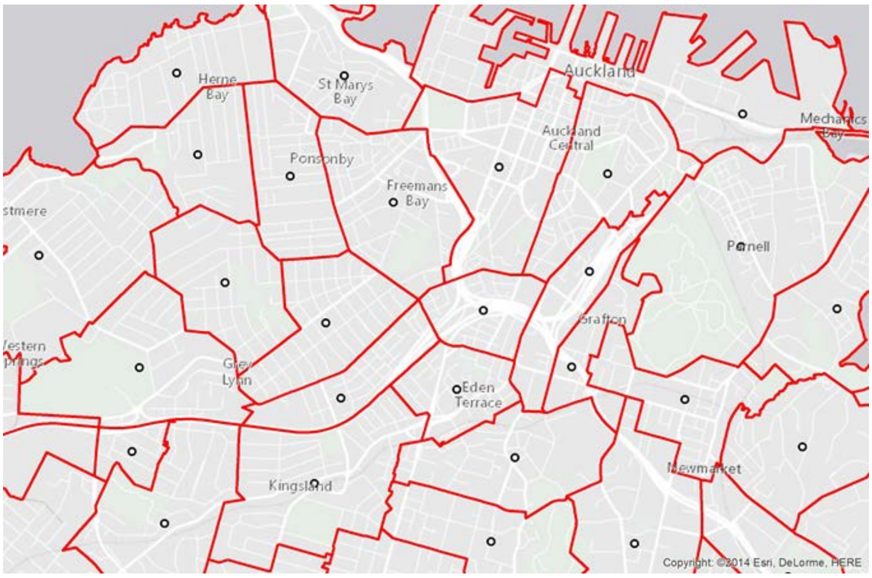
2 Attributing a relative economic value to transport network segments by assessing the relative commute flow volumes using different network segments and weighting this volume by an average income measure for employment location. This provides an assessment of the value of the journey proportional to the value of the economic output produced.[28]

C1 Modelling commute flows

The spatial distribution of passenger commuting flows can be modeled using census data on origin and destinations of trips to work (ie a dataset on travelling from a person's home, or origin, to work, their destination). This is most appropriately completed at a regional labour-market scale.

Using Auckland for illustrative purposes, we construct a commute flow model using Census 2013 data, which was taken on Tuesday 5 March. The data provides information about workplace and home address. For our model, we aggregate data to the spatial scale of census area units (CAUs), rather than using precise addresses. CAUs vary considerably in spatial size and population size with an average residential population of around 3,500 people. There are 403 CAUs in the Auckland region (excluding area units covering islands). The CAUs for central Auckland are illustrated together with the location of the centroids used for our modelling purposes in figure C.1**.**

Figure C.1 Census area units and centroid locations in central Auckland

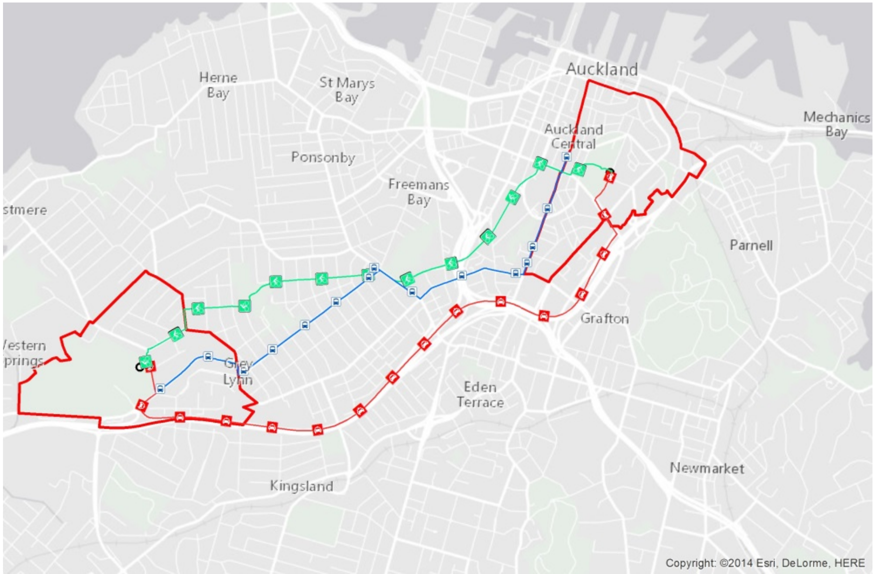


28 We use wages as a proxy for the marginal productivity of the worker, a standard assumption in economics.

We allocate all commute trips to an origin and destination defined by the CAU within which the home and workplace are located. This results in trips allocated to a matrix of 403 potential origins by 403 potential destinations.

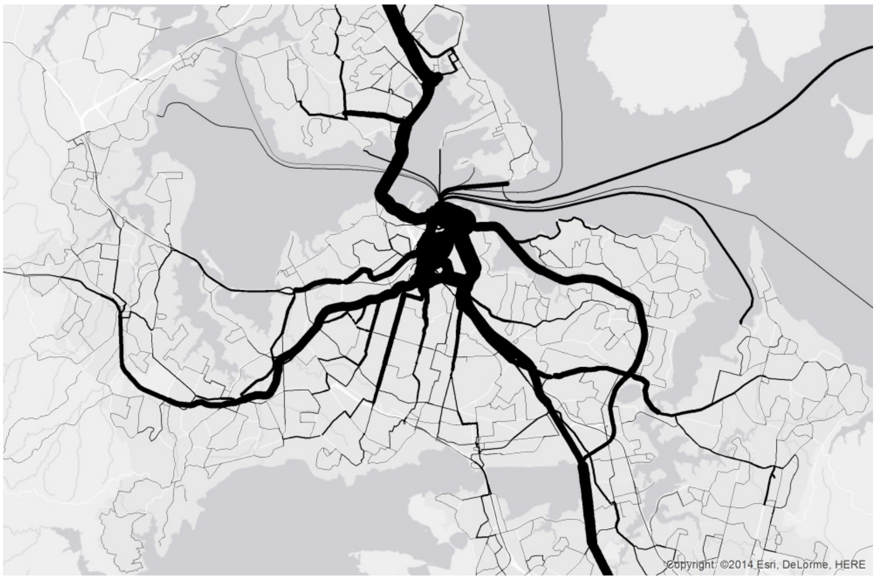
We model travel routes between the centroids of area units, rather than particular addresses, attributing commute trips to routes that represent the shortest travel times between area units. To complete this task we first construct a basic transport network by calculating the shortest trips between CAUs by each mode. Figure C.2 shows the route networks constructed for car (red line), public transport (blue line) and walking modes (green line) between two example area units to illustrate how routes are selected. The routes follow the fastest travel time between centroids, based on road speed limits and scheduled public transport travel time (from GTFS data).

Figure C.2 Example of identifying fastest routes for different modes between census area unit centroids



We then allocate trips by mode to the route network we have constructed between all CAUs. The final result of this step is data on trip volume for each road segment across Auckland. Total trip volume for PT trips across Auckland is illustrated in figure C.3.

Figure C.3 Total public transport commute trips volumes between all area units



C2 Attributing economic value to commute flows

The second stage of our analysis is to attribute an economic value to the identified commute flow volumes. The purpose of this step is to obtain a relative rather than absolute indicator of the economic value of the identified commute trips. As such, our analysis does not provide information about the actual value of the road for commuting, but does allow for a comparative ranking of value based on a proxy indicator.

We use income data at the workplace destination as a proxy indicator for the value of commute trips. We use median wage income at workplace locations (matched to CAUs) to reflect the relative productivity of firms in a specific area and the economic value of enabling workers to access these jobs. For example, the result of this analysis is likely to place a higher value on trips serving city centre areas with higher average wages demonstrating the economic value of roads serving high wage, high productivity areas. A likely result is to place lower value on roads serving lower wage, lower productivity areas.

We attribute value to commute flows by weighting each individual trip by the median individual income of the area unit within which the person works (destination). We then sum the weighted values of all trips on a particular route segment to identify a relative economic value of all commute trips on the segment.

A simplified example is described to illustrate the method. The route from area unit A (home) to B (work) is used by 30 car commuters and the median individual income of people working in area unit B is $80,000. The value of commute trips or the 'commute output' of the route is 30*$80,000 = $2.4 million. In comparison the route from area unit C (home) to D (work) is also used by 30 car commuters, however the median income of people working in area unit D is lower at $50,000. The value indicator for this route is 30*$50,000 = $1.5 million. The indicator suggests that route A-B provides 60% more economic value for commute purposes than route C-D.

Appendix D: Freight output indicator – detailed method

This indicator aims to provide information about different roads' value in enabling freight movement. Alongside the commute output of a road, road infrastructure also makes an important contribution to economic productivity by enabling freight movement, connecting goods between businesses, to markets and to consumers. This section discusses potential methods for measuring freight outputs. It focuses solely on measuring the output of roads for moving goods.

D1 Establishing regional freight profiles

The first step is to establish a regional-scale profile of freight movement. This will reflect different mixes of commodity movements within different regions. For example, based on local economic activity, it can be expected that road freight movements in the Gisborne region may be dominated by forestry products given the region's abundance of forests, while in Auckland, manufactured and retail goods may be more important, given its role as a distribution hub for New Zealand. While every individual road segment will have a unique freight profile that depends on the land uses it serves and local economic activity, limited data availability about the composition of freight movement by road segment makes regional-scale, rather than micro-scale analysis, the most feasible.[29]

Regional-scale profiles of freight movement can be developed using data on intra- and inter-regional freight movement from the *National freight demand study* (NFDS) (MoT 2014)[30]. This data is based on modelled, rather than actual commodity flows. The data provides information on freight flows for 21 selected commodity groups that aim to represent all freight movement. Example commodity groups include; 'Manufactured dairy products', 'Limestone, cement, concrete and fertiliser' and 'Imported cars'.

For illustrative purposes, table D.1 outlines how a regional-scale freight profile can be built up from NFDS data on freight tonne kilometres travelled. The output of this stage of analysis would be a freight profile for each region, showing the proportion of freight tonne kilometres by each of the 21 commodity groups. Allocating the NFDS data to each region would require consideration of the following:

- allocating all intra-regional freight to the relevant region
- allocating inter-regional freight between neighbouring regions equally between the two relevant regions
- allocating inter-regional freight that moves across multiple regions proportionally to the distance travelled through each region.

---

[29] Sensible estimates of the economic activity at a local scale could be made, using area unit data on business counts and the number of employees at a fine grained industry classification from Statistics New Zealand's business demography dataset. However, assumptions must still be made on the routes for the freight movements within and between area units.

ERoads tracks individual heavy vehicles using GPS to simplify the process required to comply with road user regulations and collate data for road user charges. As a result, ERoads collects data on the movements and exact location of heavy vehicles on a turn by turn basis. The data set includes speed, distance, stop and start time, and idling time. However, it does not include data on the freight carried by heavy vehicles. Furthermore, ERoads does not cover all heavy vehicle transportation, rather it offers a sample of the industry.

[30] Note that the 2014 NFDS was an update of the 2008 NFDS, but is in itself a separate and new report.

Table D.1 Illustration of calculating regional freight profiles[31]

	Auckland	Northland	Wellington	Auckland	Northland	Wellington
Commodity group	**million tonne kms**	**million tonne kms**	**million tonne kms**	**percent of total**	**percent of total**	**percent of total**
Liquid milk	1	3	0.1	2%	14%	1%
Timber	3	15	4	6%	70%	30%
Meat	0.1	0.5	0.2	0%	2%	2%
Manufactured goods	20	1	4	41%	5%	30%
Retail goods	25	2	5	51%	9%	38%
Total	49.1	21.5	13.3	100%	100%	100%

D2 Establishing average freight values for regions based on freight profiles

The second step is to use the regional freight profiles to establish a regional-scale average value of freight. This requires assuming an average value for each tonne of a particular commodity group. Average values can be obtained by using StatsNZ trade data on the value and weight of imports and exports of various commodities. This may not be a simple exercise given inconsistency between the NFDS and trade data commodity categories.

Table D.2 illustrates how average commodity values (per tonne) can be used to calculate a weighted average value for freight in each region. In the illustration, the average value of a tonne of freight moved in Auckland is four times higher than for Northland due to the higher proportion of more valuable retail and manufactured goods in the regional freight mix.

D3 Applying average values to road segment heavy vehicle volumes

The final step is to apply the average regional-scale freight values to road freight traffic indicators to obtain an indicator of the relative freight 'output' of each road segment. Heavy vehicle counts may needed to be adjusted for bus numbers on urban routes where buses constitute a significant proportion of heavy vehicle counts.

Table D.3 illustrates how freight output indicators can be obtained by applying regional freight value rates to AADT (heavy vehicle) indicators for each road segment.

[31] Tables D.2 and D.3 use illustrative, not actual figures, and not all 21 commodity groups used in the NFDS are listed.

Table D.2 Illustration of calculating average regional freight values[32]

		Proportion of total freight			Weighted value		
Commodity group	**Value per tonne**	**Auckland**	**Northland**	**Wellington**	**Auckland**	**Northland**	**Wellington**
Liquid milk	$5,000	2%	14%	1%	$102	$698	$38
Timber	$500	6%	70%	30%	$31	$349	$150
Meat	$7,000	0%	2%	2%	$14	$163	$105
Manufactured goods	$15,000	41%	5%	30%	$6,110	$698	$4,511
Retail goods	$12,000	51%	9%	38%	$6,110	$1,116	$4,511
Total[33]		100%	100%	100%	$12,367	$3,023	$9,316

Table D.3 Illustration of calculating relative freight outputs for road segments

Road segment	AADT	AADT (heavy vehicle)	Region	Freight value	Freight output	Relative output
SH16 – Grafton Gully	45,000	3,600	Auckland	$12,367	$44,519,756	90.0
Dominion Road	30,000	2,000	Auckland	$12,367	$24,733,198	50.0
SH20 – Airport	25,000	4,000	Auckland	$12,367	$49,466,395	100.0
SH1 Whangarei	20,000	2,500	Northland	$3,023	$7,558,140	15.3
Local rural road	1,000	50	Northland	$3,023	$151,163	0.3
SH1 inner city	35,000	2,000	Wellington	$9,316	$18,631,579	37.7
Local urban road	20,000	2,000	Wellington	$9,316	$18,631,579	37.7

[32] Note that table D.2 uses illustrative rather than actual figures.

[33] Totals may differ due to rounding.

Appendix E: Input costs – detailed methods

Section 5.4 tests the calculation of input costs for a selection of road corridors in Auckland. This appendix provides further details about the data and parameters used for this task.

In order to implement these calculations for selected Auckland roads, we created a GIS database that integrated the following key sources of data:

- Three datasets on road networks: OpenStreetMap (which provides information on free-flow traffic speeds); LINZ data on national road networks; and Auckland Council zoning maps of the size/spatial extent of roads
- GTFS data on Auckland's public transport network, including data on service-kilometres, frequencies, and stops
- Land valuation data from Auckland Council's 2011 ratings database, grouped up by 2013 Census meshblocks[34]
- Road crashes from the Transport Agency's CAS, geocoded to individual roads/intersections
- HAPINZ estimates of the annual health costs (principally increased mortality and morbidity) associated with particulate matter emissions from transport at an area unit level.

We also included several sources of data on transport volumes in our GIS database:

- Traffic volume data (light and heavy vehicles) at traffic monitoring sites on state highways and local roads
- For Auckland, HOP card public transport boardings, alightings and inferred passenger flows matched to individual PT routes[35].

Table E.1 summarises some key factors that we used to estimate the costs of providing and maintaining corridors. A key finding from this initial analysis was that deriving an estimate of the average current value of roads within a region is possible but not optimal. Using an average current value per kilometre is likely to obscure considerable variations between roads. Consequently, in further stages of work it would be preferable to investigate more detailed sources of data on the current value of roads, such as the Transport Agency's RAMM database.

Table E.1 Key variables used in analysis of capex and opex costs for transport networks

Variable	Value	Source/notes
Discount rate/annual rate of return on land and capital assets	6%	EEM
Average current asset value of roads ($/km):		
Local roads in Auckland	$1.05m/km	According to AT's 2015–2018 Asset Management Plan[36], AT

[34] Auckland Council updated its ratings valuations in 2014. In many cases this resulted in significant increases in property values. We use the earlier data as it was available from a previous project for Auckland Council. Due to the fact that there are often many rating units on a given site (or vice versa), it is best to group data by meshblock to avoid irregularities.

[35] See http://transitflows.mrcagney.webfactional.com/ for an example of how this works.

Variable	Value	Source/notes
		manages 7,302km of local roads with a total current (depreciated) value of $7.68bn. We used these figures to calculate the average value per kilometre.
State highways	$1.56m/km	According to the Transport Agency's 2012–2015 State Highway Asset Management Plan[37], the Transport Agency's state highways have a current (depreciated) value of $16.96bn, excluding the value of land. There are a total of 10,886km of state highways in New Zealand[38]. We used these figures to calculate the average value per kilometre.
Average annual maintenance, operating and renewal (MOR) expenditures ($/km):		
Local roads in Auckland	$29,500/km	Based on the Transport Agency's regional expenditure data for the MOR activity group[39] and the Transport Agency's maintenance cost index[40], we estimate that local authorities in Auckland spent an annual average of $107.7m, in real terms, on MOR over the 2005–2014 period. We further assume 50% funding assistance from the NLTF[41]. We used these figures to calculate the average annual spending per kilometre of local road.
State highways in Auckland	$183,000/km	Based on the Transport Agency's regional expenditure data for the MOR activity group[42] and the Transport Agency's maintenance cost index[43], we estimate the Transport Agency spent an annual average of $163.2m on MOR, in real terms, in Auckland over the 2005–2014 period. We subtracted the estimated funding assistance for local road MOR and divided this out across Auckland's 303km of state highways[44].
Annual Public Transport Operating Costs	$1.99/ service km	PT service subsidies for Auckland were $114 million in 2014. Annual service kilometres for PT were 57 million. We use these figures to calculate an average cost per service kilometre.

[36] Available online at https://at.govt.nz/media/1182902/Item-10-1-Asset-Management-Plan-2015-2018.pdf

[37] www.nzta.govt.nz/assets/resources/state-highway-asset-management-plan/docs/state-highway-asset-mgmt-plan-2012-2015.pdf

[38] www.transport.govt.nz/ourwork/tmif/infrastructureandinvestment/ii001/

[39] www.nzta.govt.nz/planning-and-investment/planning/transport-data/funding/

[40] www.nzta.govt.nz/resources/procurement-manual/procurement-tools.html

[41] This is based on the annual average funding assistance rate (FAR):
www.nzta.govt.nz/assets/planning/investment/docs/far-background.pdf
Auckland's FAR has historically been slightly lower but is targeted to rise: www.pikb.co.nz/home/nzta-investment-policy/funding-assistance-policy-and-rates-for-the-2015-18-nltp/2015-18-nltp-normal-funding-assistance-rates/

[42] www.nzta.govt.nz/planning-and-investment/planning/transport-data/funding/

[43] www.nzta.govt.nz/resources/procurement-manual/procurement-tools.html

[44] www.transport.govt.nz/ourwork/tmif/infrastructureandinvestment/ii001/

Finally, table E.2 summarises the factors we use to calculate the social cost of crashes for individual road segments. We group crashes in the Transport Agency's CAS database into four categories (fatal crash, serious injury crash, minor injury crash, non-injury crash) and apply an average social cost derived from the EEM to each crash. Because crash data tends to be quite lumpy, we have looked at the annual average number of crashes over a five-year period (2009–2014).

Table E.2 Factors used to calculate the social cost of crashes

Crash type[45]	Average cost per reported crash on:		Sources
	50km/h roads	Motorway/100km/h roads	
Fatal injury	$4,154,000	$4,712,000	Calculated using EEM tables A6.21(a-h), A6.20(a,b), A12.2
Serious injury	$759,000	$954,000	
Minor injury	$93,700	$56,500	
Non-injury	$18,200	$20,800	

[45] Averaged across all movements and all vehicles.

Appendix F: Scale of analysis

Measures of the value of transport infrastructure are commonly undertaken across three scales; the national level, regional level or local level. We borrow this geographically based classification from Banister and Berechman's (2001) review of the links between transport investment and economic development. We consider this a useful framework for investigating potential enhancements to ONRC indicators as these three levels:

- reflect the scales at which economic, government and social activity is commonly organised
- reflect common ways in which transport and economic data and modelling tools are organised.

Studies of the wider economic benefits (WEBs) of transport commonly measure the impacts of infrastructure at either the national, regional or local scale. For example, there is an established literature studying the national-level effects of infrastructure on the national economy and a parallel branch of literature studying the local-level effects of infrastructure on economic welfare through property value indicators. Across these scales a range of different indicator measures are used. This section reviews these measures for their potential applicability for ONRC road classification purposes.

Banister and Berechman (2001) outline the various types of economic output measures relevant across the three scales in their table in table F.1. The methodologies used across these three scales are summarised, along with key concepts and example studies.

Table F.1 Conceptual framework of analysis

Variables	Scale of analysis		
	National	Regional	Local
Economic development measures	Productivity growth: social rate of return	Accessibility changes; changes in the location of retail, housing and employment activities	Employment level; time allocation; labour productivity
Output measures of models	Annual GDP growth	Spatial relocation; competitive advantage; industrial clustering	Growth in jobs; welfare improvement; agglomeration economies
Scale and type of transport measures	Total state capital; infrastructure stock	High-speed regional rail and road networks; regional terminals: airports, seaports, waterways, pipelines	Metropolitan roads and facilities; new rail links; underground rail; transport centres

Source: Banister and Berechman (2001) p212.

F1 National level measures for the value of transport infrastructure

At the national level, studies of the economic value of transport infrastructure are concerned with the effect of infrastructure on the national economy, specifically GDP or output. If a country invests in transport infrastructure, such as roading, does GDP change and if so by how much? Methods used by these studies may be relevant for developing indicators for the purposes of ONRC of New Zealand roads.

F1.1 Key concepts

Historically, specific transport infrastructure projects have made large positive contributions to economic development in developing countries where the projects established basic connectivity. However, in developed countries where connectivity is already well established, improvements in transport infrastructure are less likely to result in rapid economic development. Rather, improvements are considered to enable growth by releasing constraints on the economy (Eddington 2006).

Therefore, the effect of transport infrastructure on GDP is not necessarily constant. Rather it is likely to vary across time and by country.

Eddington provides a notional list of seven micro driver mechanisms, which contain a number of interacting concepts, and are further developed in his report. In summary, the micro drivers are:

- **Increased business efficiency** – through time savings and improved reliability for business travellers, freight and logistic operations.
- **Increased business investment and innovation** – by supporting economies of scale or new ways of working.
- **Supporting clusters and agglomerations or economic activity** – by expanding labour market catchments, improving job matching, and facilitating businesses to grow.
- **Improving the efficient function of labour markets** – by increasing labour market flexibility and the accessibility of jobs through employment mobility.
- **Increasing competition** – by opening up access to new markets.
- **Increasing domestic and international trade** – by reducing the costs of trading.
- **Attracting globally mobile activity** – by providing an attractive business environment and a good quality of life.

As well as these seven micro driver mechanisms, transport infrastructure also impacts on a population's welfare through:

- environmental impacts
- reduced travel times
- improved safety
- improved leisure and social opportunities.

Although many studies have attempted to measure the relationship between transport infrastructure and GDP, two main criticisms have been raised (Banister and Goodwin 2011):

- Studies assume increased output increases GDP and the rate of investment in infrastructure (the input) is not influenced by other factors not controlled for in the model.
- The direction and existence of causality is not established. Causality relates to the direction of the relationship between transport infrastructure and GDP. Specifically, does investment in roads cause economic growth, does economic growth lead to investment in roads (or is there some interaction effect).

More recently, for developed countries with developed transport networks studies have considered there to be no assumed link between transport investment and economic development, and that benefits are likely to be marginal if they exist (Williamson et al 2012).

Banister and Berechman (2001) argue that investment in transport infrastructure is a necessary condition but not a sufficient condition for economic development. They consider transport infrastructure to be a 'complement to other more important underlying conditions' (p210). They outline three necessary conditions for economic development to occur:

- **underlying positive economic externalities** – including agglomeration and labour market economies, a good quality labour force, underlying local economic conditions
- **investment factors** – including availability of funds for investment, scale and location of the investment, and its timing and efficiency of implementation
- **political factors** – the broader policy environment that investment decisions are taken place in must be conducive to an investment.

F1.2 Example studies

Most studies that have estimated the effect of transport infrastructure on GDP have done so at the national level (or, in some cases, at the regional or state level within countries) by comparing the total stock of road infrastructure to GDP. It has been less common for studies to value individual road segments, although there are some emerging techniques based on changes to accessibility and accessible 'economic mass' (eg Byett et al 2015).

These studies generally model transport infrastructure, or public capital more generally, as an input into the economy's 'production function'. In other words, they analyse the relationship between various inputs to production, including public and private capital and labour, and economic output, or GDP. Growth in GDP depends on increases in inputs (capital or labour), or increases in productivity (SACTRA 1999).

Aschauer (1989a) and Aschauer (1989b) use production function analysis to estimate the link between public sector investment and productivity growth. Aschauer (1989a) (as cited in SACTRA 1999) estimates the elasticity of output with respect to public infrastructure capital of 0.4. This implies a 10% increase in the public infrastructure stock increases output by 4%. However, Aschauer (1989a) does not identify how investment in transport infrastructure affects output, making it difficult to assess the findings fully. More recent studies have found smaller effects, closer to 0.1–0.2.

Model specification can vary between studies. Time series and panel models are common in the literature. However, Kamps (2004) uses a vector autoregressive (VAR) model to estimate the dynamic effects of public capital for 22 OECD countries between 1960 and 2001. VAR models allow for fewer restrictions to be placed on the interactions between model variables, eg VAR models allow increases in GDP to increase public investment in transport infrastructure, and vice versa[46]. Kamps uses a four variable VAR model that includes: public net capital stock, private net capital stock, the number of employed persons and real GDP.

He finds that:

- for most countries, shocks to public capital had positive output effects
- there was little evidence of the 'supernormal' returns to public capital that has been documented in the previous literature
- for the majority of countries analysed, public and private capital are long run complements (short run results were mixed)

[46] However, VAR models entail a trade-off – as additional variables are added to the model, the degrees of freedom falls which can raise the bar for identifying statistically significant relationships.

- for most countries, the long run response of employment to a shock to public capital was statistically insignificant.

For New Zealand, Kamps (2004) estimated a long-run elasticity of real GDP with respect to public infrastructure investment of 0.11. This suggests a 10% increase in the public capital stock increases real GDP by 1.1%. However, this is not statistically significant at the 95% or even the 68% level of significance. Wallis (2009) summarised the findings of Kamps (2004) and other studies (recreated in table F.2 for New Zealand and Australia).

Table F.2 Comparison of New Zealand and Australian evidence on responsiveness to public infrastructure investment[47]

Study	Study type and scope	Elasticity of GDP/output with respect to public infrastructure investment
New Zealand results:		
Kamps (2004)	VAR model, 22 OECD countries including New Zealand	0.11
Australian results:		
Kamps (2004)	VAR model, 22 OECD countries including New Zealand	0.29[(a)]
Otto and Voss (1996) (cited by Econtech 2004)	Australia	0.17
Pereira (2001) (cited by Econtech 2004)	Australia	0.17
Kam (2001)	Australia	0.17
Song (2002)	Australia	0.29–0.39
NIER (2001)	Production function, Australia	0.18
Song (2002)	CGE model, Australia	0.13

[(a)] Significant at the 68% level. Relevant to the Kamps (2004) result only.

F1.3 Relevance for ONRC purposes

Previous studies using this approach have generally looked at the economic value of entire infrastructure networks, or new investments in infrastructure, at a national level. This methodology is not well suited for disaggregating the relative contribution of different links within a network to economic outcomes. It is not therefore likely to be useful for the purpose of classifying different road segments for the ONRC.

[47] Table adapted from Wallis (2009, p74).

F2 Regional level measures for the value of transport infrastructure

F2.1 Key concepts

Regional-level analysis investigates the non-transport benefits at the regional or local level. The central tenet of analysis at this level is that imperfect markets give rise to externalities, such as agglomeration economies, which are not accounted for in traditional transport appraisal. Banister (2007) briefly outlines the four types of benefits, agglomeration effects, labour market imperfections, network economies and environmental effects, which can result from transport investment. Banister and Berechman (2001) note the importance of accessibility, from transport investment, as a factor that drives the redistribution of employment.

As previously discussed, agglomeration economies are benefits which result from the geographical proximity of firms to each other. Mare and Graham (2009) describe agglomeration economies as the 'productive advantages that arise from the spatial concentration of economic activity' (p7).

There is a wealth of literature on the sources of agglomeration and the mechanisms through which agglomeration economies benefits arise[48]. The focus of more recent literature has been to understand the mechanisms for agglomeration benefits, to understand how to target transport policy.

Duranton and Puga (2003) outline three micro-foundations of agglomeration economies, based on sharing, matching and learning mechanisms, and formulate models for each. The theory and mechanisms are simplified in Puga (2010:

- Sharing facilities refers to large fixed cost goods or facilities. As the population grows to use the goods or facilities, the lower the cost per user.
- Sharing suppliers refers to the larger common base of intermediate producers (who are able to specialise) in larger cities.
- Sharing the gains from individual specialization refers to the classic pin factor example, as individuals can specialise in a narrower set of tasks.
- Sharing a labour pool refers to the readily available supply of workers with the required skills, which an industry can take advantage of.
- Better matching refers to the better matching of skilled workers and the skillset desired by employers.
- Learning refers to the transfer and creation of knowledge between firms and between employees and firms.

Density underpins all the mechanisms, specifically employment density. There is broad consensus in the literature that there is a positive relationship between productivity and urban concentration. Rosenthal and Strange (2004) as cited in Puga (2010) suggest that a doubling of city size increases productivity by between 3% and 8%. Melo et al (2012) find a doubling of employment density leads to an increase of 4.3% in average wages in the US. Table 1 in Graham (2007) shows the range of results from (predominantly) analyses of US, Swedish, Japanese, Brazilian metropolitan statistical areas or city level. The estimated elasticity of productivity from increasing urban concentration ranged from 0.01 to 0.2 (for manufacturing industries).

[48] The sources of agglomeration thinking trace back to Marshall (1890).

Local research also suggests a strong positive relationship between density and productivity measures. Williamson et al (2008) suggest that doubling employment density would increase average incomes by 9.9% (Williamson et al 2008) and Mare (2008) suggests a slightly smaller relationship on productivity of 5.4%.

F2.2 Example studies

Venables (2007) establishes a theoretical model to estimate the agglomeration impact from transport provision, linking access to economic density to the amount that productivity will increase by. Transport investment increases access to economic mass, the change in which determines the new economic density firms have access to. The productivity improvements are given by the agglomeration elasticities.

The practical estimation of agglomeration benefits for transport projects all use changes in economic mass (as measured by a change in employment density, for example) as a result of a transport project as a first step, and then assessing the impact of the change in economic mass on productivity.

The UK Department for Transport used a model similar to that outlined in Venables (2007) for the London Cross Rail project, employing an approach that combined the elasticity of productivity due to employment density and the change in effective job density in an area due to a project. The approach used the change in the generalised cost of travel between two areas as the basis of the change in effective density.

SDG, as cited in Graham (2007), assesses a range of proposed transport projects in the Yorkshire and Humberside region of England, using the same agglomeration elasticities found in Graham (2005).

Central to the analysis is robust estimates of agglomeration elasticities. Agglomeration elasticities for New Zealand have been estimated by Mare and Graham (2009), as noted earlier. These have been included in the EEM.

Kernohan and Rognlien (2011) use the agglomeration elasticities by Mare and Graham (2009) in their assessment of the agglomeration benefits of the Additional Waitemata Harbour Crossing. Kernohan and Rognlien (2011) use an average generalised cost metric to the effective density calculation, and in turn specify the effective density of a zone as the sum of the total employment weighted by the generalised cost of accessing jobs in that zone.

F2.3 Relevance for ONRC purposes

The conditions for agglomeration economies may not necessarily exist for all roads, rendering a regional-level analysis difficult across all levels of the ONRC. Typically, only large urban projects have the necessary conditions for agglomeration economies to arise. Taking a step back to the well-known Marshallian trinity, it is not likely that, for example, rural roads will always:

- enable greater economies of scale in production
- encourage greater worker specialisation and labour market pooling
- improve the probability of knowledge spillovers.

In this situation, a regional-level analysis would not distinguish between roads where economic mass does not change dramatically, as there is insufficient economic density in rural areas.

In addition, the data requirements would be onerous, small area accessibility measures (eg generalised cost) before and after a road is established, is the key data outstanding. It would be difficult to retrospectively estimate the change in generalised cost of a road.

F3 Local-level measures for the value of transport infrastructure

Micro scale analysis of a road's contribution to economic welfare focuses on local or neighbourhood scale impacts of a road to assess its economic value. Examples of micro scale analysis include property value impact analysis of road infrastructure or retail activity analysis on properties adjacent to a road. This section summarises the key concepts underlying these forms of analysis, discusses some examples of such analysis in use and assesses the relevance of these approaches for ONRC functional classification purposes.

F3.1 Key concepts

Micro scale analysis of the economic impacts of transport infrastructure has often focused on property value change following the introduction of new infrastructure as a way of assessing the economic benefits of the infrastructure. While property value effects have been most commonly measured at the micro scale, other spatially-defined indicators at the local or neighbourhood scale could potentially be used to assess how road infrastructure contributes to economic welfare. For example, indicators of economic productivity could be alternative measures to property value impact analysis. While much of the existing work on micro-scale analysis has been applied to assess new infrastructure improvement projects, there may be opportunities to apply equivalent concepts to assess the relative value of different components of existing infrastructure networks. Property value analysis has been more often applied to assessment of public transport infrastructure (particularly rail) rather than road infrastructure. Nevertheless, the conceptual framework is common across all types of transport infrastructure.

With regard to property value analysis of transport infrastructure, the theoretical basis of these methods lies within the urban economics literature (eg Alonso 1964; Muth 1969). Spatial equilibrium and bid-rent theory places considerable weight on the role of transport costs and differential levels of accessibility in determining differential land values throughout cities. Focusing firstly on commuting transport costs, in a traditional mono-centric city where employment is concentrated in the central business district (CBD), residential land values can be expected to decline with distance from the CBD as commuting costs rise. Conversely, higher residential land values close to the CBD reflect transport time-savings capitalised into higher land values. The spatial distribution of road infrastructure (together with other types of transport infrastructure) creates a differential landscape of accessibility to employment centres which can be expected to be accompanied by differential residential property prices. While most cities have dense road networks allowing for reasonable accessibility across a wide range of locations, infrastructure such as high speed motorways can have significant effects on the spatial distribution of accessibility and accompanying land values.

Likewise for commercial and industrial property, transport accessibility will be one factor among many that influences the productivity and desirability of particular locations. Locations well served by road infrastructure will enjoy higher land values, with precise affects differing among industry sectors and land uses. For CBD commercial office and retail property served by passenger transport infrastructure, purchasers can be expected to bid up the price of property in these central locations that benefit from improved accessibility to labour markets, suppliers and customers (McCann 2001). Industrial property values may be more influenced by good motorway accessibility and links to freight networks and logistics hubs. While property value analysis has more commonly been undertaken in urban contexts, the principles are also relevant for infrastructure in non-urban locations.

Improved accessibility can have second-order impacts by increasing the potential for agglomeration externalities that can further contribute to property value uplift. Transport accessibility supports agglomeration externalities at particular locations by enabling a greater ease of interaction between higher numbers of people and firms, increasing the 'economic mass' accessible from a location or its 'effective density' (Venables 2007). The property value impacts from agglomeration externalities are likely to be most significant for CBD locations in large congested cities where dense networks of converging transport infrastructure can allow firms to benefit from denser concentrations of business activity (Chatman and Noland 2014). Agglomeration economies could also be at work in more peripheral or even non-urban locations, where infrastructure allows relatively good accessibility to longer-distance flows of business inputs.

While transport infrastructure can create positive land value effects from the accessibility benefits it provides, it can also create negative local impacts on economic welfare associated with various externalities such as noise, air pollution or nuisance. These negative effects are also reflected in land values. Within our framework for measuring the productivity of infrastructure, these negative impacts are most appropriately considered as inputs that offset a road's positive economic outputs. Further discussion of inputs is included in chapter 2.2. For example, while residential property next to a motorway interchange enjoys particular accessibility advantages that may be expected to positively impact its land value, it also may experience noise and air pollution that reduce land values. The net positive or negative effect of the infrastructure will depend on the relative strength of these advantages and disadvantages.

This example also highlights how levels of local benefits and costs associated with roads will vary significantly over short distances. While a retail outlet may benefit from being immediately adjacent to a major road with high exposure to potential customers, the same benefit will be much less if the retail property is 100m down a side street. The spatial 'decay' of accessibility benefits from roads is generally considered to extend further or reduce at a lower rate than the externality costs of the infrastructure (Seo et al 2014). The spatial distribution of benefits and disamenities from road infrastructure will also depend on the level of access available to the road. For a limited access motorway, for example, accessibility benefits will centre around interchanges (nodes), while noise and pollution disamenities will extend along the entire link (Seo et al 2014). Seo et al (2014) outline a conceptual framework that illustrates the interaction of accessibility benefits and infrastructure disamenties on the net benefit for land values over distance (figure F.1). They compare the effects arising from highways and rail infrastructure at link and node (interchange/station) locations. For example, highways generally have higher levels of disamenties (noise, pollution) than railways, yet the spatial extent of their accessibility benefit extends further as railways depend on walkable catchments, whereas highway infrastructure draws users from more extensive surrounding road networks.

Figure F.1 Conceptual framework for micro- scale impacts of infrastructure on land values

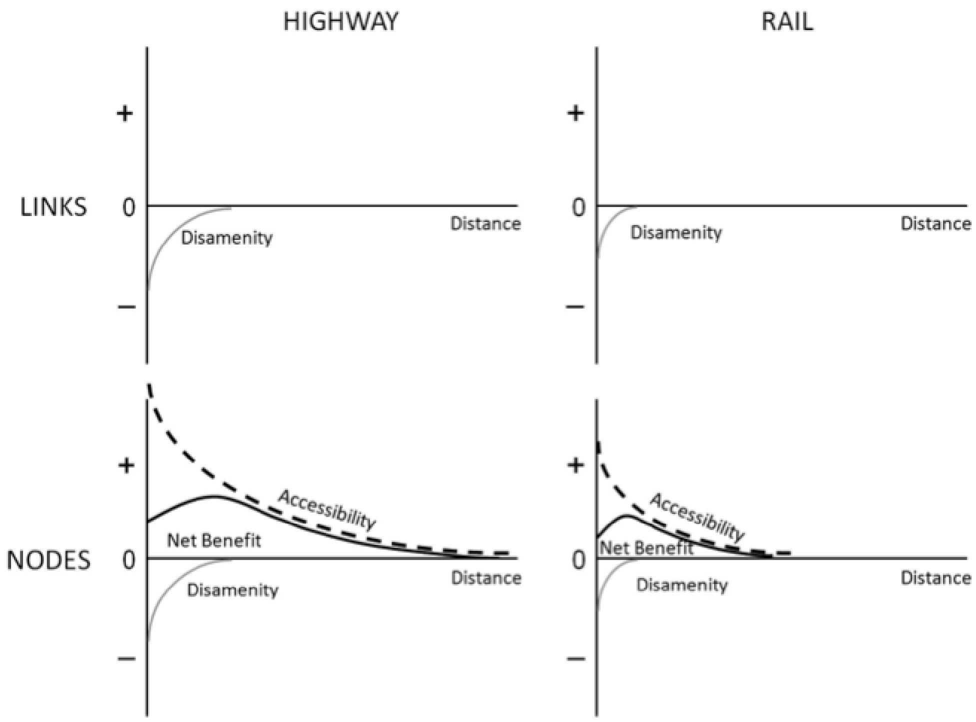


Fig. 1. Conceptual framework for net benefit of combined impacts of accessibility and disamenity.

Source: Seo et al (2014, p56).

With regard to indicators other than land value that may measure the economic impact of road infrastructure at the micro scale, a number of indicators may, in theory, be relevant. For example, micro scale spatial data on wages differentials could reflect productivity levels for commercial or industrial firms (if productivity effects of infrastructure are capitalised into wages) (Gibbons et al 2012). Data on customer demand or sales could be relevant for some industries such as retail. In all cases, isolating the impact of road infrastructure on economic performance from the impact of other variables is challenging.

F3.2 Example studies

Micro-scale analysis of the economic value of road infrastructure has been undertaken using various measures including land value impacts and firm productivity impacts. Micro scale assessment of property value impacts is not so common for road infrastructure as it is for rail infrastructure, with a now extensive literature on the property value impacts of urban rail systems (Baker and Nunns 2015). The more limited spatial extent of rail networks and their limited access points around stations make it easier to attribute value from a particular rail project compared with attributing value to denser and more extensive road networks. This section briefly reviews some studies of micro-scale analysis of road infrastructure to illustrate methodologies and findings.

Grimes and Liang (2010) study land value changes following the extension of Auckland's Northern Motorway. They use fine-grained spatial data (meshblock level) on land values, comparing levels of change between 1991 and 2006 (the period of road construction) in areas near to the motorway interchanges, and other areas of Auckland. Their analysis suggests that land values rose more strongly around interchanges than in other areas of the city, with the net land value increase attributable to the project exceeding the total capital costs of the project by a factor of 6. While they assess land value changes in locations near motorway interchanges they do not attempt to analyse other potential downstream benefits for commercial CBD properties that could also benefit from greater accessibility.

Seo et al (2014) assess both the positive and negative property value impacts of the motorway network in Phoenix, Arizona. Using hedonic pricing models for detached housing they find both positive accessibility benefits from proximity to motorway interchanges and negative disamenities. They find that total net benefits in terms of property values peak at intermediate distances from interchanges where disamenities become insignificant but accessibility benefits remain high. The study highlights the potential of micro-scale indicators to assess net economic welfare effects of transport infrastructure by accounting not only for positive benefits but also localised costs of infrastructure externalities.

Gibbons et al (2012) use micro-level spatial analysis to study road infrastructure improvement impacts on firm employment and productivity. Rather than using property value assessment to estimate the economic value of infrastructure they use firm-level indicators of economic performance. They used fine-grained spatial data from between 1998 and 2007 to assess the impact of road accessibility improvements on the number of firms, employment levels and various productivity measures. They find substantial effects from new road infrastructure, with the most robust effects measured being positive impacts on levels of employment and firm entry within locations enjoying accessibility benefits.

F3.3 Relevance to the ONRC

Micro scale analysis of roads' contribution to economic welfare holds promise in potentially allowing for more accurate attribution of economic impacts arising from infrastructure. Compared with national and regional scale approaches, contextual factors that influence final economic impacts may be more easily controlled for (Banister and Thurstain-Goodwin 2011). For example, fine-grained spatial analysis of the impacts of new infrastructure on land-values may be more easily measured than agglomeration impacts of the same infrastructure project or impacts on national level GDP.

For the purposes of the ONRC functional classsification and ranking of various roads for their economic significance, micro scale analysis of the type described above may provide opportunities for collecting more detailed information about the level of economic activity supported by the road and on land served by the road that could complement existing information about traffic flows on roads. Existing traffic flow measures could also be considered micro scale in that spatially defined information is available at a reasonably fine level of detail. The micro scale measures discussed in this section are different in focusing not on transport activity on the road, but on the value of economic activity served by the road. This may provide an advance on existing traffic volume measures in beginning to account for the differential value of equivalent volumes of passenger and freight travel across different contexts.

Nevertheless, there remain considerable difficulties in data collection, data availability and attribution of economic impacts to infrastructure with these micro scale methods. While previous studies have generally measured the economic impact of distinct components of road infrastructure (eg a limited highway system, or specific road improvement), there may be difficulties in applying these techniques to measure the relative value of an entire existing network. Unlike rail based public transport networks, for which property value impact analysis has been used extensively and can rely on limited 'impact zones', road networks are dense and extensive and there are significant network effects. Attributing value to different components of these networks may be difficult, although there may be good potential for limited access urban and rural motorways.

Avenues for further investigation of micro-scale assessment that may contribute to ONRC include:

- **Property value analysis:** comparing property values in areas served by different roads may point toward the relative importance of different road links in supporting economic activity. For example, roads that serve areas of relatively high property value (eg a large factory within a predominantly low value rural area, or a CBD with higher land values than surrounding urban areas) may point toward roads that support highly productive economic activity and therefore are more critical to social and economic wellbeing.
- **GDP/ employment analysis:** comparing spatially defined GDP or employment indicators may point toward areas where roads are supporting an intensity of economic activity, or highly productive activity. The spatial distribution of GDP may be correlated with underlying property values and so could be applied similarly for ONRC purposes.
- **Industry sector/ firm- level analysis:** using spatial data on the location of various firms across different sectors may be useful for identifying the various road infrastructure requirements of different industries. With transport demands varying substantially across industries, such information could assist optimising investment strategies to match dominant industries. For example, the transport needs of the financial services industry that enjoy advantages from micro scale walking accessibility between firms in dense inner city environments and require access to large labour pools are very distinct to the transport needs of a large scale industrial facility that may depend less on labour inputs and more on transport infrastructure that facilitate bulk commodity movements.

Appendix G: ONRC decision trees

Figure G.1 Access road decision tree

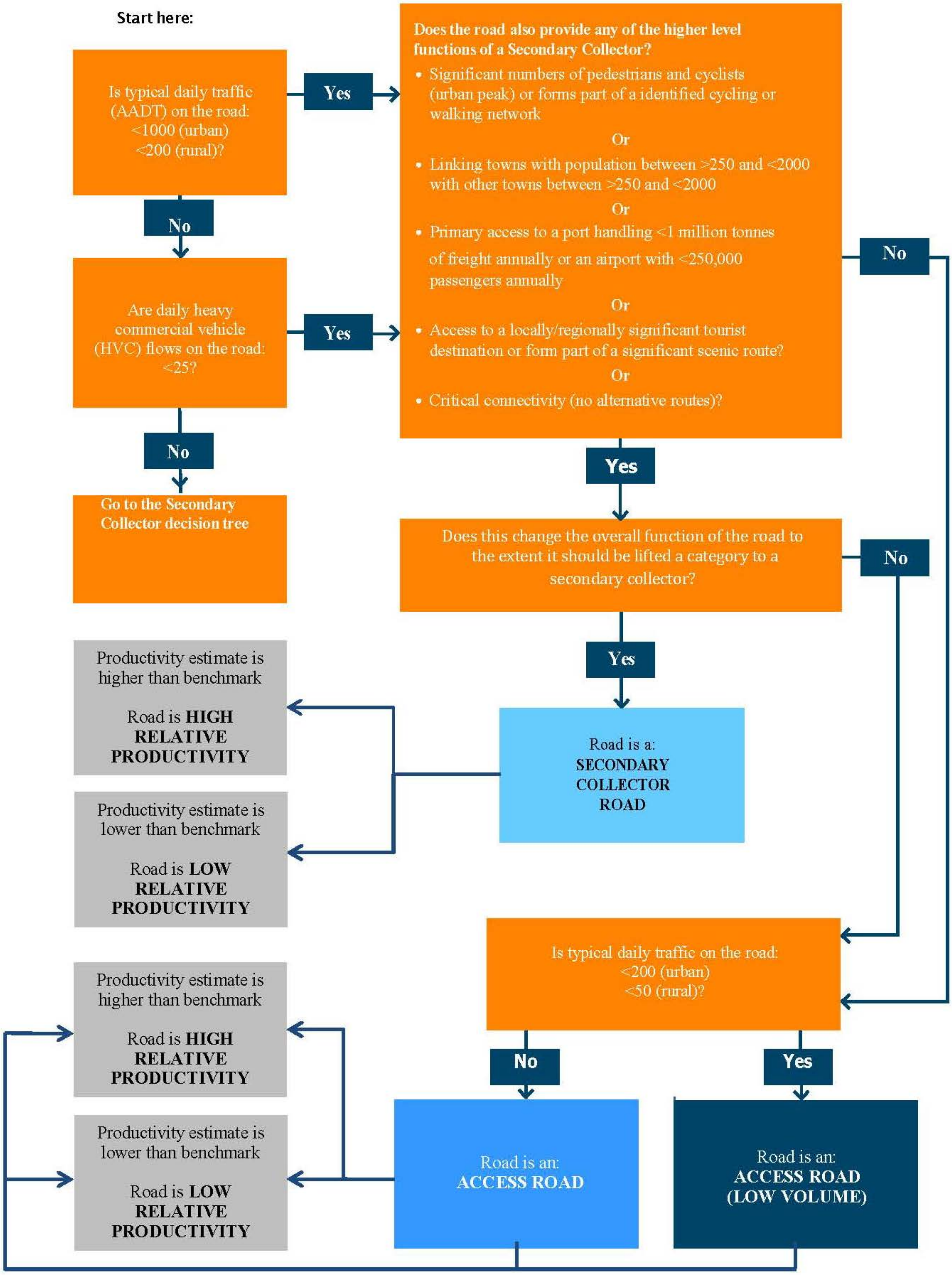


Figure G.2 Secondary collector decision tree (road must meet, at least, the ADT or HCV criteria)

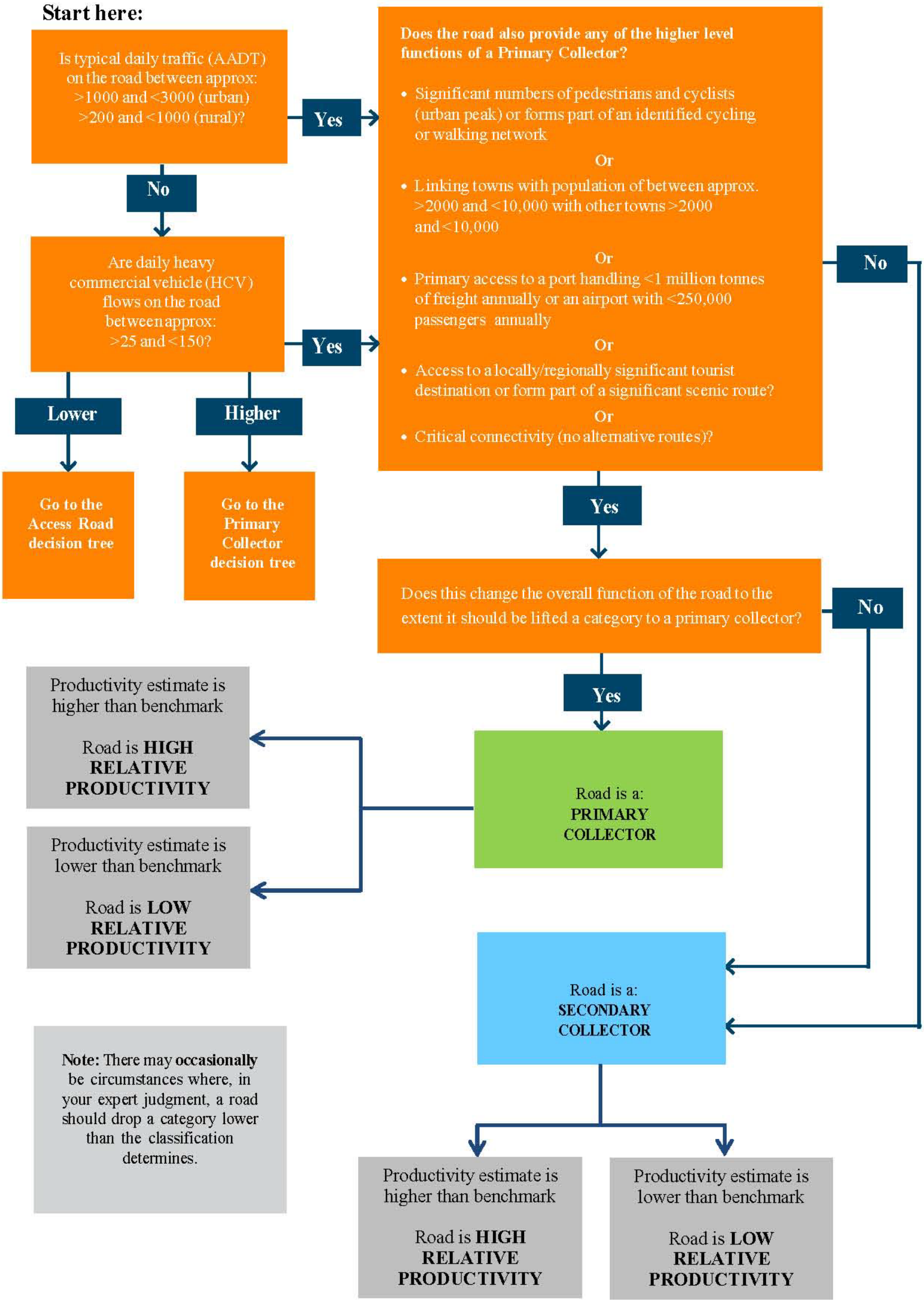


Figure G.3 Primary collector decision tree (road must meet, at least one of the ADT, HCV or bus criteria)

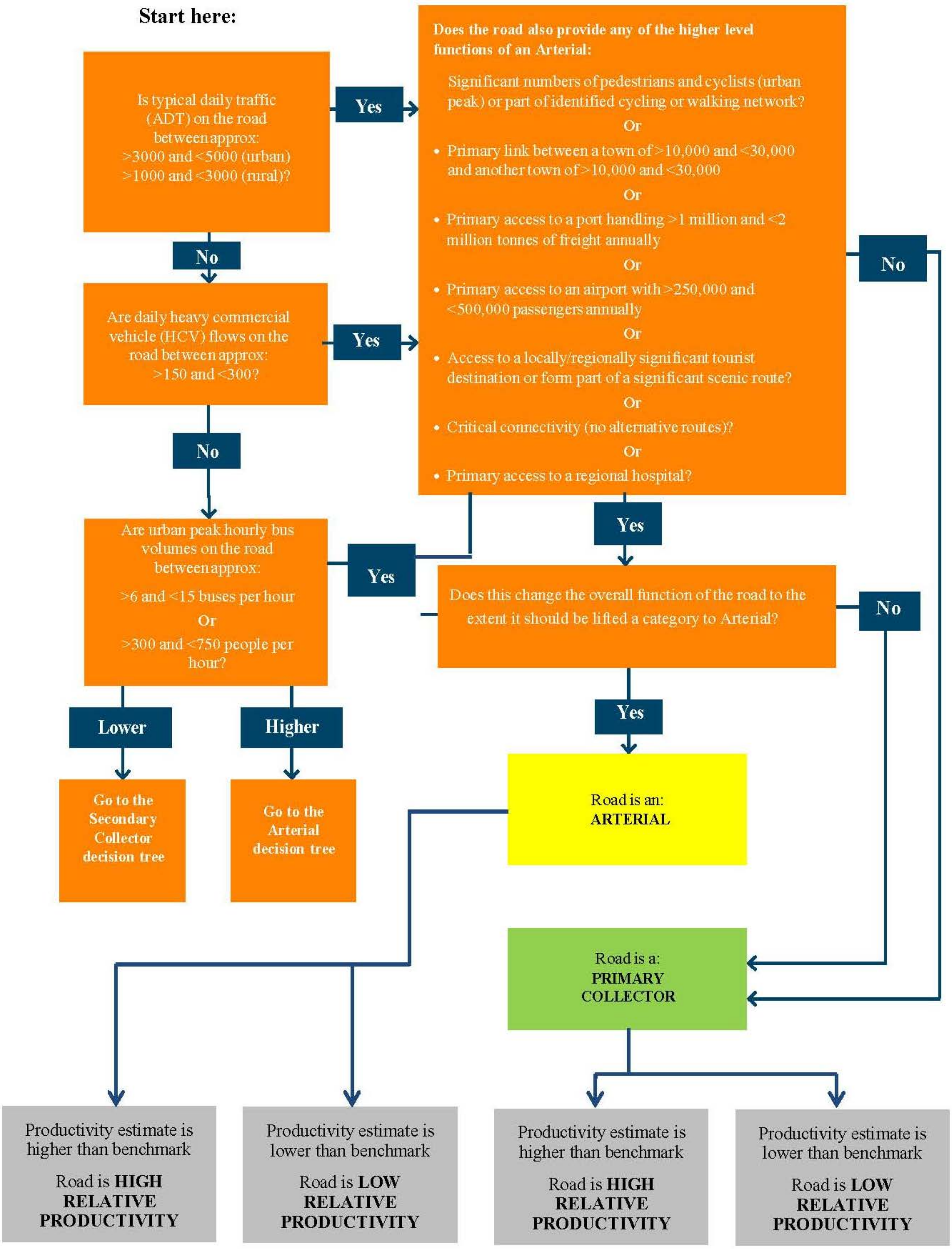


Figure G.4 Arterial decision tree (road must meet 2 criteria in total, including at least 1 from BOX 1.

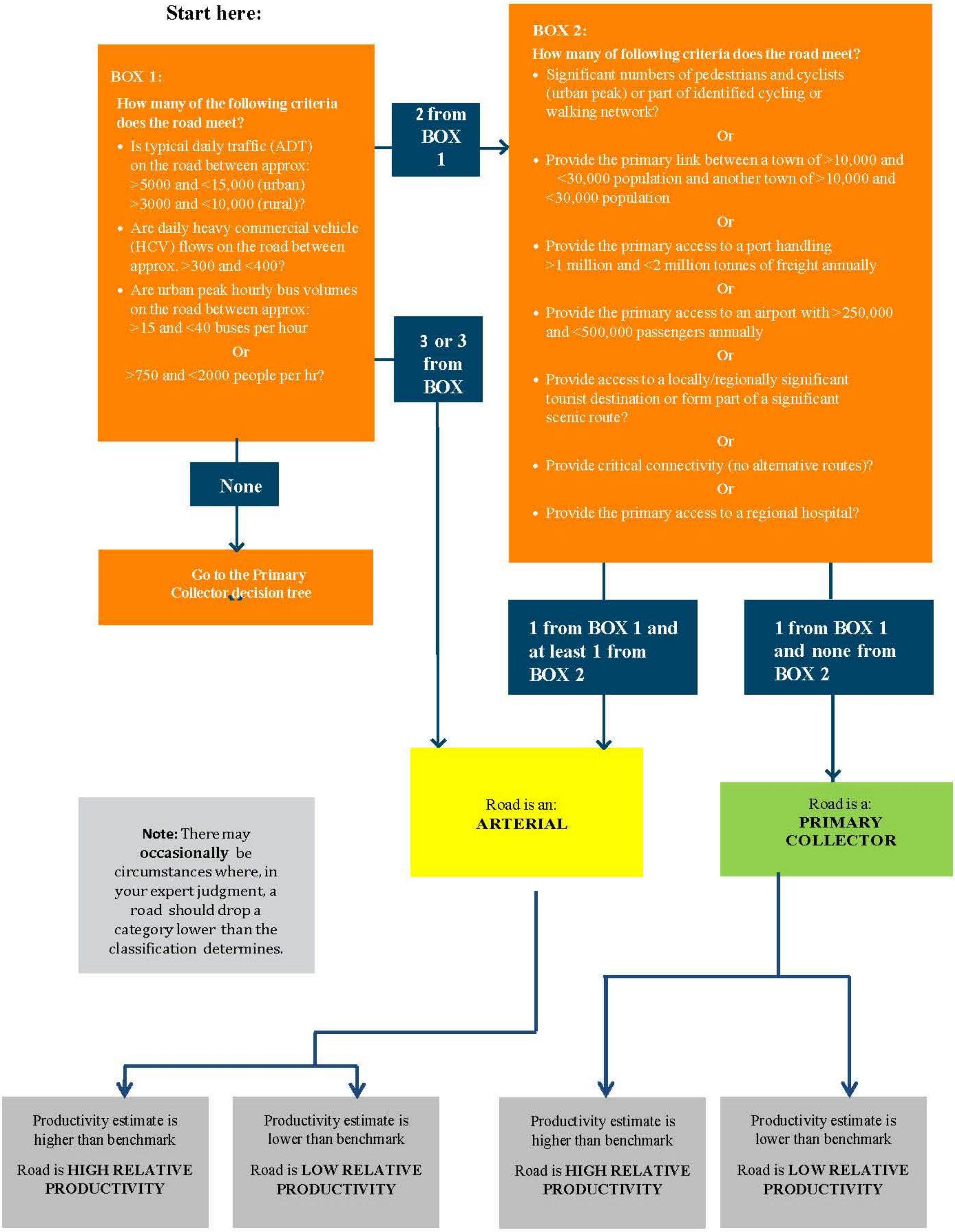


Figure G.5 Regional decision tree (road must meet 2 criteria in total – including at least 1 from Box 2)

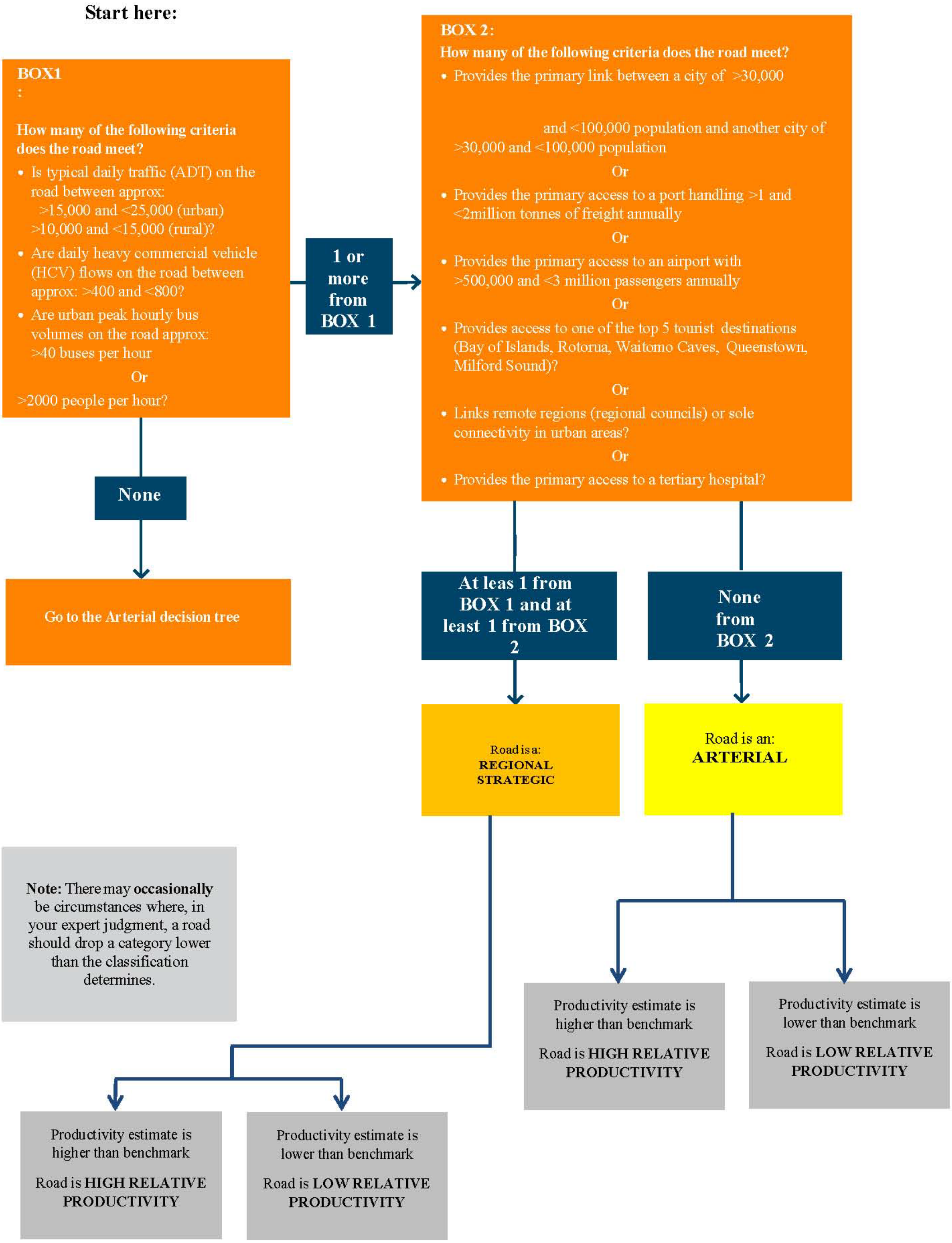
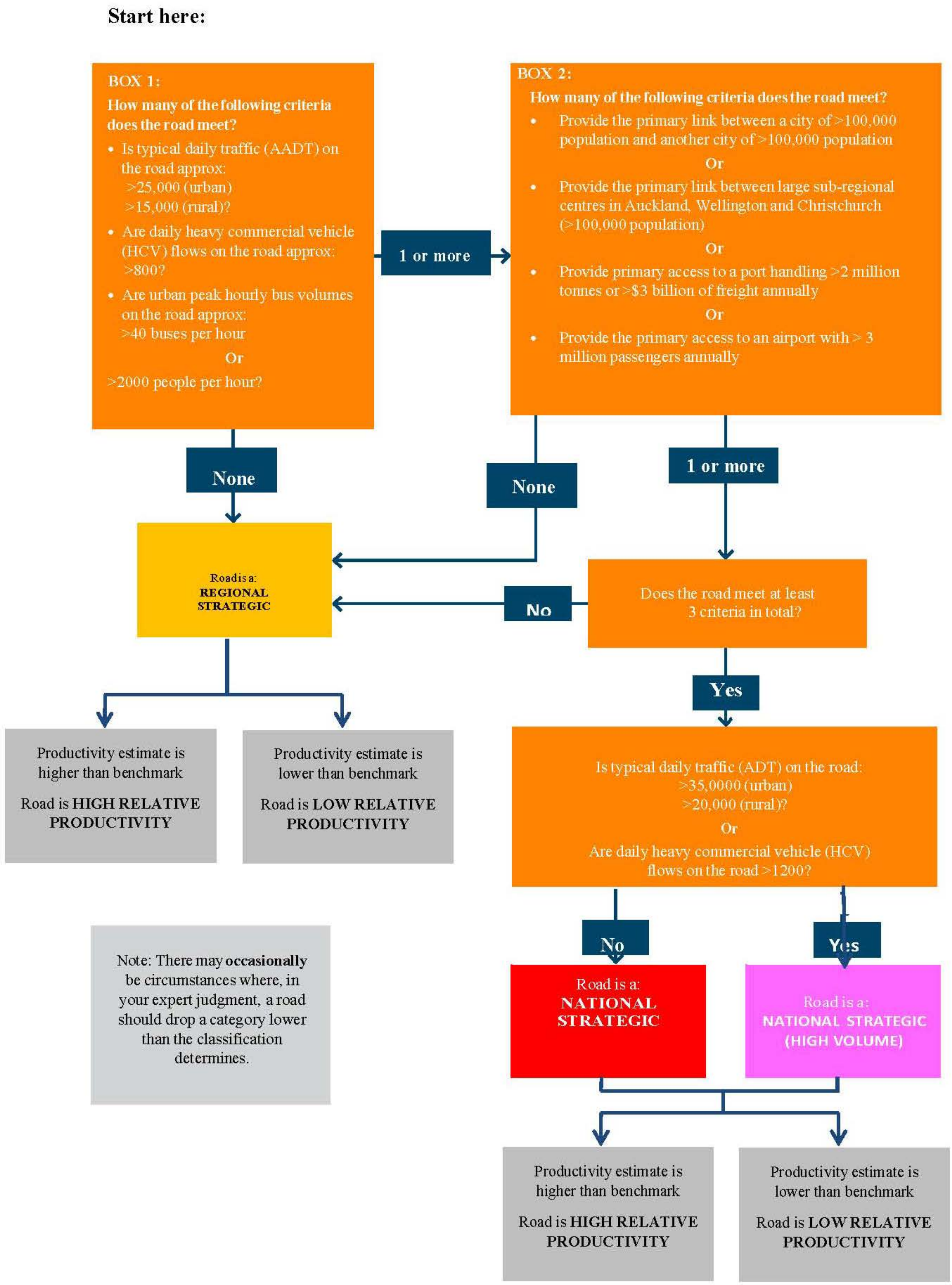


Figure G.6 National decision tree (road must meet 3 criteria in total: with at least one from Box 1 and at least one from Box 2)



Appendix H: Glossary

AADT	annual average daily traffic
ANZSIC	Australia New Zealand Standard Industrial Classification
AT	Auckland Transport
B2B	business to business
BPR	Bureau of Public Roads
CAS	Crash Analysis System
CAUs	census area units
CBA	cost-benefit analysis
CBD	central business district
GDP	gross domestic product
EEM	*Economic evaluation manual*
GIS	geographic information system
GTFS	general traffic feed specification
GVA	gross value added
HAPINZ	Health and Air Pollution in New Zealand
HCV	heavy commercial vehicle
HOP	AT HOP is the smart card system used for travel on trains, ferries and buses around Auckland
LEED	Linked Employer-Employee Database
LINZ	Land and Information New Zealand
MOR	maintenance, operating and renewal
MoT	Ministry of Transport
NFDS	National Freight Demand Study
NLTF	National Land Transport Fund
OECD	Organisation for Economic Co-operation and Development
ONRC	One Network Road Classification
pkt	passenger kilometres travelled
PT	public transport
RAMM	Road Assessment and Maintenance Management
RCA	road controlling authorities
SH	state highway
TLAs	territorial and local authorities
Transport Agency	New Zealand Transport Agency
TT	travel time
vkt	vehicle kilometres travelled
VAR	vector autoregressive
VOC	vehicle operating costs
WEB	wider economic benefits